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A HOT-WIRE ANEMOMETER STUDY OF FREE TURBULENT MIXING IN AXIAL PRESSURE GRADIENTS

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THESIS

A HOT-WIRE ANEMOMETER STUDY OF
FREE TURBULENT MIXING IN
AXIAL PRESSURE GRADIENTS

by

Michael Erwin Kearney

Thesis Advisor: G.J. Hokenson

December 1972

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A Hot-Wire Anemometer Study of
Free Turbulent Mixing in
Axial Pressure Gradients

by

Michael Erwin Kearney
Lieutenant, United States Navy
B.S., Naval Postgraduate School, 1972

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ABSTRACT

This report was prepared to describe the results of an experimental study of free turbulent mixing in axial pressure gradients. Both the pressure field and the velocity field were extracted using pitot-static probes and both a single normal wire and an X-array hot-wire anemometers. The resulting hot-wire data shown in Figures 1-80 present an excellent visual representation of the physical aspects of turbulent flow.

An analysis of the results of this experiment show conclusively that the Reynolds Stresses in the flow are related by some function to the turbulent kinetic energy; however, no specific function was found that would produce the relationship observed in this study.

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NOMENCLATURE

A_τ	Boussinesq apparent viscosity
A	X-Array hot-wire lead (u+v)
B	X-Array hot-wire lead (u-v)
C	Constant in hot-wire calculations
C_1	Constant in apparent viscosity relation
C_τ	Local turbulent shear coefficient
C_{uv}	Correlation coefficient
d	Wake generator diameter
e	Linear output from hot-wire
H	Shape factor
i,j	Indicates i or j direction (i=1,2,... j=1,2,...)
k	Turbulent kinetic energy
ℓ	Prandtl mixing length
p	Pressure
q	Dynamic pressure
r	General flow parameter
S(x)	Apparent viscosity constant
T	Characteristic time
t	Time
x,y,z	Spatial Coordinates x - Axial y - Lateral
u,v,w	Corresponding velocities
v^*	Characteristic velocity

β	Constant in hot-wire calculations
δ	Displacement thickness
δ_3	Energy thickness
ε	Mixing length parameter = $k^m \ell^n$
θ	Momentum thickness
μ	Laminar viscosity
μ_t	Apparent viscosity
ν	Laminar kinetic viscosity
ν_t	Apparent kinetic viscosity
ρ	Density
τ	Reynold's Stress
∇	Differential operator DEL
$\int_a^b dy$	Integral from a to b with respect to y
$\frac{\partial u}{\partial r}$	Partial derivative with respect to r
$\frac{du}{dr}$	Ordinary derivative with respect to r
$\lvert\ \rvert$	Indicates absolute value

Subscripts

A	Parameter of lead A on hot-wire
B	Parameter of lead B on hot-wire
e	Local external flow conditions
x,y	Indicates partial differentiation with respect to x,y
τ	Shear related quantity

Superscripts

$\overline{\quad}$	Indicates a time averaged quantity
'	Designates a fluctuating quantity

I. INTRODUCTION

In most real fluid flows the transition from laminar to turbulent flow carries the fluid mechanist from a situation where he can safely predict the values of the flow-field parameters from the solution of the Navier-Stokes Equations to one where predictions are obtainable only on the average, at best. Yet most practical applications require at least some consideration of turbulence and how it can be dealt with. In the past the engineer has assumed various plausible hypotheses in order to introduce a measure of order and predictability to turbulent flow. It is the intention of this study, then, to attempt to experimentally verify certain of these hypotheses. Before describing the currently accepted assumptions regarding turbulent flow, a general review of their history will be presented to provide the necessary background information.

A turbulent flow is defined as one in which an irregular fluctuation or mixing motion is superimposed on the principal fluid motion. Its onset is accompanied by a noticeable change in the law of resistance. In the case of laminar pipe flow, the longitudinal pressure gradient which maintains the motion is proportional to the first power of the velocity. By contrast, in turbulent flow this pressure gradient becomes nearly proportional to the square of the mean flow velocity. In order to calculate flow field values

in a turbulent field, then, some logical hypothesis must be made to account for this change in the apparent viscosity of the flow. First, it is generally assumed that the fluid motion can be separated into a mean and a fluctuating part which are linearly related to the total fluid motion in such a way that a flow parameter (r) can be defined

$$r = \bar{r} + r' \qquad \text{(I-1)}$$

These definitions can be substituted into the equations of motion to produce a new set of equations involving mean and fluctuating terms and their cross products. Assuming that the time average of the fluctuations is zero, the equations may be averaged to get the following momentum equation for a two-dimensional mean flow (see Appendix A for the complete development):

$$\bar{u}\frac{\partial \bar{u}}{\partial x} + \bar{v}\,\frac{\partial \bar{u}}{\partial y} = u_e\,\frac{du_e}{dx} + \nu_t\,(x)\,\frac{\partial^2 \bar{u}}{\partial y^2} \qquad \text{(A-22)}$$

where the apparent kinematic viscosity ($\nu_t(x)$) is a function of the turbulent flow field, and is calculated by using some logical empirical hypothesis for approximating its value.

Since only the mean values of the flow parameters are known, some means of relating these values to the Reynolds stresses produced by the fluctuating part of the flow is required. The first hypothesis for relating these quantities

was proposed by J. Boussinesq,

$$\tau_o = -\rho\overline{u'v'} = A_\tau \frac{\partial\bar{u}}{\partial y} \qquad \text{(I-2)}$$

where A_τ is an apparent or eddy viscosity that is not a fluid property but depends on the structure of the flow field.

$$A_\tau = \rho\ \nu_t(x)$$

This apparent viscosity is generally assumed to be proportional to some characteristic velocity (v^*) times the mean velocity gradient:

$$A_\tau = v^* \frac{\partial\bar{u}}{\partial y} \qquad \text{(I-3)}$$

In 1925 Prandtl made an important advance in turbulent theory by introducing the concept of mixing length and the relation,

$$\tau_t = \rho\ \ell^2 \left|\frac{d\bar{u}}{dy}\right| \frac{d\bar{u}}{dy} \qquad \text{(I-4)}$$

$$\nu_t(x) = \ell^2 \left|\frac{du}{dy}\right|$$

where

ℓ = mixing length

$\ell \left|\frac{du}{dy}\right|$ = characteristic velocity

This relation has produced relatively accurate values for some limited cases. However, this definition of the kinematic viscosity implies that it should vanish where the velocity gradient is zero, which is contradictory to experimental evidence. Several subsequent hypotheses were proposed by Taylor, Von Karman, and Prandtl himself, but they were all limited in application to free turbulent flow.

Later, in an effort to develop a universally valid model for the function μ_t, Prandtl introduced an energy-based hypothesis which was subsequently improved on by Emmons (1954), and Glushko (1965),

$$\mu_t \propto \rho\, k^{1/2}\, \ell \qquad \text{(I-5)}$$

$$k \equiv (\overline{u}^2 + \overline{v}^2)/2$$

Here k was found to be a better characteristic velocity than in the earlier mixing length hypothesis, but the length scales were difficult to ascertain. More modern theories, referred to as two-equation viscosity models, use sophisticated analytical methods to determine this length scale. The apparent viscosity is first assumed to be related to the kinetic energy. Then some hypothesis of the form

$$\varepsilon = k^m\, \ell^n$$

is made to make it possible to calculate the characteristic length. One of the most accepted of these relations was introduced by Chou in 1945:

$$\varepsilon \equiv k^{3/2}/\ell \tag{I-6}$$

$$\mu_t = C_1 \rho k^2/\varepsilon$$

Thus

$$\mu_t = C_1 \rho k^{1/2} \ell \tag{I-7}$$

It was this type of assumption which initiated the project reported here. Using both pitot-static and hot-wire anemometer sensors, an attempt was made to validate the hypothesis that shear was predominantly a function of the turbulent kinetic energy.

II. EQUIPMENT

A. WIND TUNNEL

1. General Description

The tunnel consists essentially of three major components: the inlet, the test section, and the blower as shown in Figures 81-83. The inlet was designed to contract the slow moving inlet air to a high-velocity parallel flow at the entrance of the test section. At this point, a plexiglas cylinder was introduced into the flow to generate a wake velocity defect which was then subjected to a constant adverse pressure gradient. After leaving the test section, the flow was maintained at a constant area through a length of tubing, then diffused and directed into the centrifugal blower and exhausted vertically.

2. The Inlet

The inlet section of the tunnel was composed of the inlet bellmouth, the plenum chamber, and the nozzle. Incoming air was first contracted into a two-foot square plenum section. This contraction was accomplished by the inlet bellmouth constructed from eight-inch diameter aluminum pipe halves. The corner seams were filled with a sanded epoxy fillet to effect a smooth transition of the air into parallel flow. The plenum section consisted of four two-foot square by one-foot long steel sections bolted together. Cork gaskets were inserted between the sections to prevent the influx

of air at the joints and to allow for undisturbed air flow over these junctions. A four-inch thick section of quarter-inch honeycomb was installed to straighten the air flow and prevent swirling. Next, two copper screens were inserted to reduce the ambient turbulence level in the flow. Finally, the air passed from the plenum chamber to the test section through a two-foot long steel nozzle with an exit area of forty-nine square inches (seven inches square), and produced a contraction ratio of 11.76. Static pressure ports were located on the right side of the nozzle at the inlet and exit for determination of the exit dynamic pressure.

3. The Test Section

The test section consisted of two parallel, vertical side walls separated by flexible and adjustable top and bottom walls. The flexible walls were constructed from one-eighth inch Plexiglas fastened to the nozzle with piano hinges. As described in Reference 1, these walls could be varied to produce a variety of different pressure gradients, but for this experiment they were set to create a constant adverse pressure gradient followed by a constant favorable pressure gradient.

One vertical wall was provided with thirteen slots for inserting data sensors. These slots were nineteen inches high, three-eighths of an inch wide, and spaced five inches apart. A filler plug for each slot was carefully hand milled, and polished to prevent disturbing the flow along the wall when the slots were not in use. A thin

aluminum strip was wedged over each filler plug to ensure a tight fit. When these plugs were removed to insert probes, a sliding teflon seal was used to prevent an influx of air through the slot (see Figure 84).

The other vertical wall of the test section had three rectangular access holes along the axial centerline for adjustments and measurements. In addition, as one can see in Fig. 85, thirty-three static pressure ports were inserted along the axial centerline at one-and-one-half inch intervals. A manometer bank, shown in Fig. 86, connected to these static pressure ports provided a visual indication of the uniformity of the pressure distribution, as well as indicating the presence of any regions of separation. As an additional indication of possible flow separation, several rows of tufts were attached to the walls in critical areas.

Having produced the desired environment for the type of air flow that this study was initiated to investigate, a turbulent wake velocity defect was introduced into the tunnel by placing a one-inch diameter cylinder in the inlet of the test section. In order to ensure a turbulent boundary layer at separation from the cylinder, a thin strip of abrasive, shown in Fig. 87, was attached to the stagnation line of the cylinder.

4. The Blower

After exiting the test section, the air passed through two seven-inch square, four-foot long steel sections into a diffusor and then into the blower. A centrifugal

blower operating at three thousand revolutions per minute was utilized to pull air through the tunnel. The air was then exhausted vertically through 4 sections of steel pipe which contained two dampers for the control of the total mass flow through the tunnel.

B. DATA SENSORS

1. General Description

The data for this study were taken with the three different types of probes shown in Fig. 88: A pitot static probe, a single normal hot wire probe, and an x-wire hot wire probe. A detachable traversing mechanism was used to position the probes vertically, and the values were recorded by hand or on an x-y plotter.

2. The Traverse

This apparatus was equipped with two constant speed motors to drive the mechanism across the nineteen-inch vertical span of the tunnel. The probe was clamped to a movable support on the traverse, and the vertical position measured by indexing a reference mark on this mechanism to a scale fixed to the frame of the apparatus. This scale was readable to one one-hundreth of an inch. A rack-and-pinion gearing system drove a potentiometer that was also attached to the movable support to produce an electrical position signal for the abscissa of the x-y plotter.

3. The Pitot-Static Sensor

A Prandtl-type pitot-static pressure probe Model # PBA-12-F-11-KL, built by United Sensors and measuring 81 hundreths of an inch from stem to tip, was used to obtain dynamic and local static pressures at one-tenth of an inch intervals through the wake. These pressures were read on two variable angle, water-filled U-tube manometers referenced to atmospheric pressure. This reference was chosen to reduce the fluctuations in the water levels. As described in Reference 1, taking P-total minus P-static directly creates very large fluctuations that make accurate data taking difficult. By separating the two readings, the fluctuations in the manometer were significantly reduced, but not eliminated.

A third manometer was attached to the plenum chamber of the tunnel, and referenced to the last static pressure port on the test section. As one can see in Fig. 89, all of these manometers were equipped with portable plastic sights which restricted one's line of sight to a plane perpendicular to the manometer, thus precluding possible parallax and assuring consistent readings.

4. The Normal Wire

This sensor, shown in Fig. 90, was a single-wire anemometer probe, Model # 1150 built by Thermo-Systems Inc. (TSI), measuring 4 inches from stem to tip. Again the probe was fixed to the traverse for data collection. The lead

from the sensor was connected to a 1054A-30 anemometer module with a 1051-2 monitor and power supply, also built by Thermo-Systems Inc. (TSI) (See Fig. 91 & 92), which converted the voltage changes to readable data. Next these data were fed into a TSI 1015C correlator that was used to separate the alternating and D.C. signals (see Appendix B). The output of the correlator was connected to an analog data processing computer which indicated the mean square average output of the correlator. Finally, the output of this apparatus was connected to the ordinate of the X-Y plotter, recalling that a potentiometer on the traverse was connected to the abscissa.

5. The X-Wire Anemometer Probe

The last sensor, a Model # 1055 built by TSI, consisted of two hot wires oriented at 45° to the axis of the probe such that the output signals of the wires corresponded to u + v and u - v respectively (See Appendix B). These data were processed in the same manner as the normal wire data except for the use of several additional algebraic functions of the 1015C correlator.

III. EXPERIMENTAL PROCEDURE

A. GENERAL DESCRIPTION

The previous study described in Reference 1 had configured the test section to produce a constant, adverse-favorable pressure gradient. Since this was the environment required for this study, no changes were made in the test section except to ensure a tight seal between the vertical and the movable walls by the addition of strips of clay along the lines of contact.

The actual collection of data was carried out in three distinct steps. First, the pitot-static system was used to collect the total and static pressure data that were introduced into the computer program, described in Appendix E, and used to calculate the flow parameters. Next, a normal-wire anemometer was inserted in the test section to gather information on both the mean and fluctuating axial velocities. These hot-wire values were converted to velocities by equating the maximum voltage at each station to the maximum value of the velocity calculated from the pitot-static data. Finally, an X-array hot-wire anemometer probe was used to get both mean and fluctuating data for velocities in both the axial and the lateral directions, as well as Reynolds stresses. Throughout the experiment a constant wind tunnel speed was maintained by ensuring that the total pressure of the Plenum chamber, minus the static pressure from the test

section, was no less than 9.90 nor greater than 10.00 inches of water on a thirty-degree inclined manometer.

B. PITOT-STATIC DATA

In this phase of the experiment all data were recorded (to an estimated accuracy of one one-hundreth of an inch) from water-filled U-Tube manometers connected to the pitot-static probe. At each of eleven stations downstream from the cylinder the static and total pressures were recorded at intervals through the wake of one-tenth of an inch. At each station the probe was moved near the upper limit of the traverse and situated in the free stream, then the traverse was marched across the flow, recording the values of total and static pressure at each increment. The initial determination of the freestream was accomplished by observing that the manometer becomes almost totally insensitive to changes in the vertical direction in the undisturbed flow. A change in total pressure of less than three one-hundredths of an inch for three consecutive positions was taken to be the edge of the wake defect.

As the traverse approached the center of the wake the intensity of the turbulence became so large that accurate readings were difficult to obtain due to fluctuations in the water level. However, by observing the water levels for a long period of time one could determine an average height that is estimated to be accurate to three one-hundredths of one inch. The same criterion was used at the bottom of the

flow channel, as at the top, to determine when the freestream had been reached.

C. AXIAL FLOW ANEMOMETER DATA

The probe used in this phase was a single normal hot-wire anemometer designed to produce voltage changes corresponding to velocity fluctuations in the flow. When the tungsten wire was exposed to the air in the wind tunnel it was cooled by the flow over it, thus requiring additional voltage to maintain a constant temperature in the wire. It is apparent, then, that the velocity in the tunnel is proportional to the voltage required to maintain a constant temperature in the hot-wire. The probe is placed in a bridge circuit in the TSI module, and its output linearized to produce a linear function of velocity of the form:

$$e = c\ (\overline{u} + u') \qquad \text{(III-1)}$$

where,

$u = \overline{u} + u'$

$\overline{u}$ = mean flow velocity

u' = fluctuating velocity

and

$$\int_0^T u'\ dT \equiv 0 \qquad \text{(III-2)}$$

Therefore if the DC output on the correlator is selected, the output would be

$$e = c(\bar{u} + u')$$

However, since this signal was a strong function of time, the data were averaged using a low pass filter with a time constant (T) equal to 0.6 secs. The final output of the averager was simply

$$\bar{e} = c\bar{u} \qquad \text{(III-3)}$$

and this quantity was plotted versus the traverse position.

The second type of data for this phase was taken with the selector switch of the correlator on AC, thus producing an output corresponding to the fluctuating portion of the flow:

$$e' = cu' \qquad \text{(III-4)}$$

This signal was also a strong function of time but, because of the nature of the term u', as expressed in (III-2), the signal could not be directly averaged. Therefore, in order to provide a finite measure, u' was first squared and then averaged and plotted versus the traverse position, since

$$\frac{1}{T} \int_0^T (u')^2 \, d\tau \neq 0$$

Once a plot of $\bar{e}$ and e' had been obtained, the velocity could be calculated by solving equations (III-3) and (III-4) to get

$$\bar{u} = 1/C \, \bar{e}$$

$$\overline{u'^2} = \frac{1}{C^2} \overline{e'^2}$$

where from equation (B-5) in Appendix B

$$C \doteq \frac{\overline{e_e}}{\overline{u_e}} \qquad \text{(III-5)}$$

In order to produce accurate values for $\bar{u}$ and u' in the laboratory environment the equipment had to be carefully adjusted for each individual flow. Specific instructions for this procedure can be found in the TSI operational manual but, in general, the first step was to adjust the control resistance to balance the bridge circuit. This adjustment was accomplished by setting the control resistor to a value that would produce a specified voltage change on the monitor. At this point the system was ready to run and the next step was to select the linearized operational mode on the monitor, position the probe in the free stream, and maximize the frequency response of the wire by setting the inductance to the minimum value that would not cause the signal to oscillate. The stability of the system was

monitored during this step on a dual-beam oscilloscope to ensure no oscillations were present in the signal. When the probe had been adjusted to the flow a digital voltmeter was used to check the multiplier-averager for correct operation. Then the x-y plotter was set to record the signal on an appropriate scale.

Now that the system had been checked for correct operation, it was positioned as close to the upper wall as practicable and the pen was dropped on the plotter. The sensor was then driven across the wake to a point near the bottom wall, and the pen lifted. After changing the paper in the plotter, the same procedure was used to make a traverse back to the top of the test section. A total of four traverses were made at each station to record both the mean flow and the mean square of the fluctuating flow. Each of these quantities was recorded at two different scales in order to facilitate translation into digital data for the IBM-360.

D. TWO-DIMENSIONAL ANEMOMETER DATA

The basic operation and accuracy checks of the x-array hot wire are very similar to those of the single normal wire. However, some additional complications are created by having two separate wires on the probe. The terms are now defined,

$$e = \bar{e} + e'$$

$$u = \bar{u} + u'$$

$$v = \bar{v} + v'$$

As explained in Appendix B, the outputs of the two wires (A & B) were

$$e_A = C_A (u + v)$$

$$e_B = C_B (u - v)$$

Thus, for a given flow, the values of C_A and C_B cannot be determined easily. In order to find these constants one must have

$$C_A = C_B = C$$

In this study the author used a basic physical characteristic of pipe flow to set these constants equal, i.e., that the lateral velocity must be zero at the centerline. Recall that, at $y = 0$

$$e_A = C_A u = C_B u = e_B$$

Thus the calue of $(e_A - e_B)$ was set equal to zero so the constant (C) could be defined as in (III-5). Note that this procedure is equivalent to setting $V = 0$ at the centerline since,

$$e_A - e_B = C(u + v) - C(u - v) = 2Cv$$

$$e_A + e_B = C(u + v) + C(u - v) = 2Cu$$

The actual position of the centerline was determined from the pitot-static data taken in phase 1.

Again, the wires were adjusted to the individual flow at each station and the data were taken in the same manner as described in the previous section. However, several more traverses were required to get all of the data available to the x-array hot wire. The settings on the correlator, and the corresponding flow parameters, are listed below. All barred quantities were taken with the correlator on DC, and averaged before plotting. The primed quantities were taken with the correlator on AC, and squared, averaged, and then plotted.

SETTING	RESULT	SETTING	RESULT
$(\overline{A+B})$	$\overline{u}$	$\overline{(A+B)'^2}$	$\overline{u'^2}$
$(\overline{A-B})$	$\overline{v}$	$\overline{(A-B)'^2}$	$\overline{v'^2}$
$\overline{A}$	$\overline{u+v}$	$\overline{A'^2}$	$\overline{(u+v)'^2}$
$\overline{B}$	$\overline{u-v}$	$\overline{B'^2}$	$\overline{(u-v)'^2}$

IV. DISCUSSION OF RESULTS

Since this study was intended to carry out an investigation of free turbulent mixing in a constant pressure gradient, it would be appropriate to discuss how close the actual experimental environment approached that desired for the study. It can be easily seen in Fig. 21 that a wake velocity defect was initially created by the cylinder as desired, and the magnitude of $\overline{u'^2}$ in Fig. 41 clearly shows that the flow was, in fact, turbulent. However, it can also be seen that the adverse pressure gradient encourages the formation of a large boundary layer which, as it mixes downstream, interacts with the wake defect, tending to raise some doubt that free turbulent mixing is still present downstream of Station 6. It is especially significant to note that the turbulence near the wall builds up from a negligible value at Station 1 (see Fig. 41-50) to a value greater than that induced into the wake by the cylinder midway down the test section. As expected, the wake defect eventually begins to mix out in the favorable pressure gradient.

By comparing the stress calculated from the pitot-static data with that from the hot-wire anemometer, one can easily see that in both cases the stress is zero on the centerline, then builds up to a maximum as the velocity gradient nears the region of its maximum. At the later stations, both

types of data show a shear stress sign reversal, and its magnitude begins to increase as the traverse approaches the edge of the test section. This trend in the data was probably reflecting the increasing interaction with the boundary layer as the air flowed downstream.

Due to the greater capabilities of the hot-wire probe, it was used to take data very near the wall, and the velocity can be seen to fall rapidly in the vicinity of the boundary layer. The hot-wire data (Figures 1-80) were then used to prepare Table I to display the value of the correlation coefficient (C_{uv}) and η in the turbulent flow field. Note that the correlation coefficient C_{uv} approaches zero at the centerline, and reaches its maximum where the shear is a maximum as predicted by Schlicting (See Fig. 18.4 Ref. 2).

Considering the relation between kinetic energy and the shear stress, it is easy to see in Table II that both parameters reach a maximum at nearly the same point in the flow. Comparing the anemometer with the pitot-static data in Appendix F, the maximum shear there also occurs at the lateral position corresponding to the kinetic energy maximum. Thus, it is clear that at least some significant functional relationship exists between them. The ideal relationship would be that postulated by the theory of eddy viscosity, that the two parameters differ only by a constant that is a function of x. The slight displacement of the two maximums in this case would imply that the relationship between

k and C_τ is, in reality, a more complex function. As an additional attempt to clarify the relation between kinetic energy and shear stress, equation (7) was approximated by taking the characteristic velocity as the square root of the kinetic energy, and

$$S = C_1 \ \ell = S(x) \qquad \text{(IV-1)}$$

As a result, the relation for Reynolds stress becomes,

$$\frac{\tau_k}{\rho} = \mu_t \frac{\partial \bar{u}}{\partial y} = S(x)\ k^{1/2} \frac{\partial \bar{u}}{\partial y} \qquad \text{(IV-2)}$$

The values for equation (IV-2) were calculated and plotted versus traverse position for several stations from the data in Table II, which was derived from Figures 21-80. The results of these plots are shown in Figures 93-97. Once again, there is a definite similarity between the results of the approximating equation, (7), and the calculation of $\overline{u'v'}$ from the hot wire data. In this case the shapes of the curves were exceptionally similar, but the maximums were still displaced by a small amount, preventing direct correlation by multiplication by a constant. The author feels that a more comprehensive analysis of the data in this report is warranted by the obvious visual relationship of the curves. An in-depth analysis might well uncover a significantly better model for calculating turbulent flow fields than are currently in use.

TABLE I

Calculation of The Correlation Coefficient and Eta

$$C_{uv} = \frac{\overline{e_A'^2} - \overline{e_B'^2}}{\sqrt{(e_A+e_B)'^2}\,\sqrt{(e_A-e_B)'^2}} \qquad \eta = \frac{2\left(\overline{e_A'^2} + \overline{e_B'^2}\right)}{(e_A+e_B)'^2 + (e_A-e_B)'^2}$$

Position	C	η
	Station 1	
10.5	-.6529	1.310
11.0	-.4881	1.341
11.5	-.4353	1.494
12.0	-.2092	1.745
12.5	-.0319	1.812
13.0	.1501	1.782
13.5	.2857	1.489
14.0	.3112	1.292
14.5	.1631	1.243
	Station 2	
9.5	-.4045	.9032
10.0	-.4170	1.250
10.5	-.2029	1.012
11.0	-.2353	.9706
11.5	-.2470	1.058
12.0	-.3108	1.243

Position	C	η
12.5	-.0381	1.219
13.0	.1172	1.249
13.5	.1880	1.188
14.0	.2576	1.343
14.5	.0851	1.277
15.0	.0683	1.153
15.5	-.2887	.875
Station 3		
9.0	-.4544	.878
10.0	-.3404	.922
11.0	-.3661	1.122
12.0	-.2401	1.227
13.0	.0915	1.281
14.0	.1889	1.211
15.0	.1097	1.071
Station 4		
8.0	-.6876	1.108
9.0	-.5699	1.281
10.0	-.4562	1.361
11.0	-.3599	1.426
12.0	-.1709	1.472
13.0	.0983	1.474
14.0	.2615	1.485

	4 (cont.)	
Position	C	η
15.0	.2815	1.314
16.0	.2400	1.194
17.0	-.0423	1.036
	Station 5	
8.0	-.2750	1.083
9.0	-.3340	1.176
10.0	-.3470	1.317
11.0	-.3040	1.341
12.0	-.1508	1.388
13.0	.0582	1.427
14.0	.1907	1.390
15.0	.2584	1.317
16.0	.1848	1.161
17.0	-.0418	1.105
	Station 6	
7.0	-.0154	1.145
8.0	-.2951	1.125
9.0	-.2809	1.165
10.0	-.2711	1.269
11.0	-.4096	1.119
12.0	-.0900	1.254
13.0	.0295	1.374

6 (cont)		
Position	C	η
14.0	.2051	1.296
15.0	.2327	1.283
16.0	.1704	1.212
17.0	.0461	1.049
Station 7		
7.0	.0684	1.103
8.0	-.1341	1.109
9.0	-.2719	1.158
10.0	-.3906	1.291
11.0	-.2718	1.279
12.0	-.1534	1.228
13.0	.0857	1.264
14.0	.2013	1.306
15.0	.1845	1.243
16.0	.1131	1.176
17.0	.0246	1.048

Station 8		
Position	C	η
7.0	.1517	1.144
8.0	-.1027	1.010
9.0	-.3392	1.138
10.0	-.7895	1.095
11.0	-.7298	1.194
12.0	-.3909	1.205
13.0	.1279	1.165
14.0	.4510	1.232
15.0	.2654	1.200
16.0	.0634	1.151
17.0	-.4360	1.185
Station 10		
9.0	.0454	1.095
10.0	-.7389	1.130
11.0	-.8439	1.079
12.0	-.3313	1.080
13.0	.2910	1.091
14.0	.4818	1.105
15.0	-.0229	1.145
16.0	-.0116	1.020

Station 9		
Position	C	η
9.0	-.3614	1.123
10.0	-.6485	1.063
11.0	-.7565	1.130
12.0	-.3710	1.091
13.0	.1835	1.143
14.0	.5674	1.146
15.0	.3130	1.140

TABLE II

Calculation of Kinetic Energy And Shear Stress Parameters

$$\overline{u'v'} = \beta^2\left(\overline{e_A'^2} - \overline{e_B'^2}\right) \qquad k = \beta^2\left[\overline{(e_A+e_B)'^2} + \overline{(e_A-e_B)'^2}\right]$$

	Station 1	
Position	k	$\overline{u'v'}$
12.8	993.9	36,81
13.0	965.0	70.99
13.2	928.2	84.14
13.4	870.3	94.66
13.6	780.9	115.69
13.8	657.3	89.40
14.0	512.7	78.88
14.2	331.3	47.33
14.4	239.3	34.18
14.6	155.1	13.15
	Station 2	
12.0	535.0	-83.0
12.5	545.0	10.4

Station 2 (cont.)		
Position	k	$\overline{u'v'}$
12.8	534.0	20.74
13.0	531.4	31.11
13.2	521.0	36.29
13.4	505.5	31.11
13.6	466.6	20.74
13.8	414.8	7.78
14.0	362.9	5.18
14.2	311.1	2.59
14.4	267.0	5.18
14.6	223.0	5.18
14.8	189.3	7.78
15.0	153.0	5.18
Station 3		
12.4	378.5	-22.08
12.6	376.9	-11.04
12.8	376.9	3.15
13.0	380.1	15.77
13.2	381.7	28.39
13.4	378.5	28.39
13.6	364.3	29.97
13.8	343.8	29.97

Station 3 (cont.)		
Position	k	$\overline{u'v'}$
14.0	320.2	29.97
14.2	296.5	23.66
14.4	265.0	22.08
14.6	236.6	17.35
14.8	205.0	12.62
15.0	176.6	9.46
15.2	135.6	6.31
15.4	119.9	3.15
Station 4		
13.0	235.9	11.53
13.2	237.5	16.14
13.4	238.2	21.52
13.6	237.5	25.36
13.8	235.1	27.66
14.0	232.8	29.97
14.2	226.7	32.28
14.4	219.0	30.74
14.6	209.8	25.36
14.8	199.0	23.05
15.0	186.0	19.98
15.2	172.9	16.91

Station 4 (cont.)		
Position	k	$\overline{u'v'}$
15.4	156.8	16.91
15.6	139.9	12.30
15.8	139.1	10.76
16.0	101.4	8.45
16.2	86.1	7.69
16.4	72.2	6.15
16.6	61.5	3.84
16.8	52.3	3.84
Station 5		
12.0	217.5	-14.32
12.2	214.8	- 8.05
12.4	213.0	- 3.58
12.6	213.0	0.90
12.8	215.7	4.48
13.0	217.5	7.16
13.2	221.0	11.63
13.4	224.6	14.32
13.6	228.2	17.00
13.8	230.0	19.69
14.0	232.7	21.48
14.2	231.8	24.16
14.4	229.1	25.95

Station 5 (cont.)		
Position	k	$\overline{u'v'}$
14.6	226.4	25.95
14.8	221.9	25.95
15.0	214.8	26.85
15.2	208.5	26.85
15.4	197.8	26.85
15.6	187.9	24.16
15.8	176.3	21.48
16.0	166.5	17.90
16.2	152.1	14.32
16.4	137.8	11.63
16.6	125.3	8.95
16.8	107.4	1.79
17.0	93.97	- 1.79
17.2	85.0	- 2.69
17.4	78.8	- 3.58
Station 6		
13.0	191.1	2.71
13.2	197.5	6.34
13.4	202.0	10.87
13.6	205.6	13.59
13.8	208.4	18.12
14.0	211.1	20.84

Station 6 (cont.)

Position	k	$\overline{u'v'}$
14.2	212.0	23.55
14.4	212.0	24.46
14.6	211.1	24.46
14.8	208.4	23.55
15.0	204.7	22.65
15.2	199.3	21.74
15.4	193.9	22.65
15.6	188.4	19.02
15.8	181.2	16.31
16.0	174.8	13.59
16.2	164.0	10.87
16.4	153.1	7.25
16.6	144.9	5.44
16.8	135.0	3.62
17.0	129.5	2.72
17.2	121.4	0.0
17.4	116.9	- 3.62
	Station 7	
13.0	169.3	10.87
13.2	173.9	14.49
13.4	178.4	17.21
13.6	182.9	18.11

Station 7 (cont.)

Position	k	$\overline{u'v'}$
13.8	188.4	18.11
14.0	192.9	18.11
14.2	195.6	18.11
14.4	198.3	18.11
14.6	198.3	18.11
14.8	215.0	18.11
15.0	193.8	17.21
15.2	190.2	17.21
15.4	184.7	15.40
15.6	180.2	14.49
15.8	173.9	11.77
16.0	169.3	9.06
16.2	163.9	8.15
16.4	158.5	7.25
16.6	154.0	6.34
16.8	151.3	4.53
17.0	148.5	1.81
17.2	147.6	- 3.62
17.4	149.4	-10.87
17.6	154.9	-16.30

Position	k	$\overline{u'v'}$
Station 8		
15.0	171.8	11.34
15.2	170.1	9.60
15.4	166.6	9.60
15.6	164.0	7.85
15.8	159.6	5.23
16.0	156.1	2.62
16.2	151.8	- 1.75
16.4	148.3	- 5.23
16.6	147.4	- 9.60
16.8	150.0	- 14.83
17.0	160.5	- 18.32
Station 9		
12.0	136.4	-13.22
12.2	133.1	- 9.92
12.4	131.4	- 5.79
12.6	131.4	- 1.65
12.8	133.9	2.48
13.0	138.8	6.61
13.2	140.5	10.74
13.4	143.8	14.05
13.6	147.1	17.36
13.8	151.2	20.66

Station 9 (cont.)		
Position	k	u'v'
14.0	152.9	21.49
14.2	152.1	20.66
14.4	149.6	19.83
14.6	147.1	16.53
14.8	143.8	14.88
15.0	142.1	11.57
Station 10		
12.0	123.0	-10.66
12.2	119.7	- 6.56
12.4	119.7	- 1.64
12.6	121.4	2.46
12.8	124.6	6.56
13.0	126.3	9.84
13.2	132.0	13.94
13.4	135.3	16.40
13.6	138.6	18.04
13.8	141.1	19.68
14.0	140.2	17.22
14.2	138.6	15.58
14.4	138.6	12.30
14.6	137.8	7.38
14.8	136.1	3.28

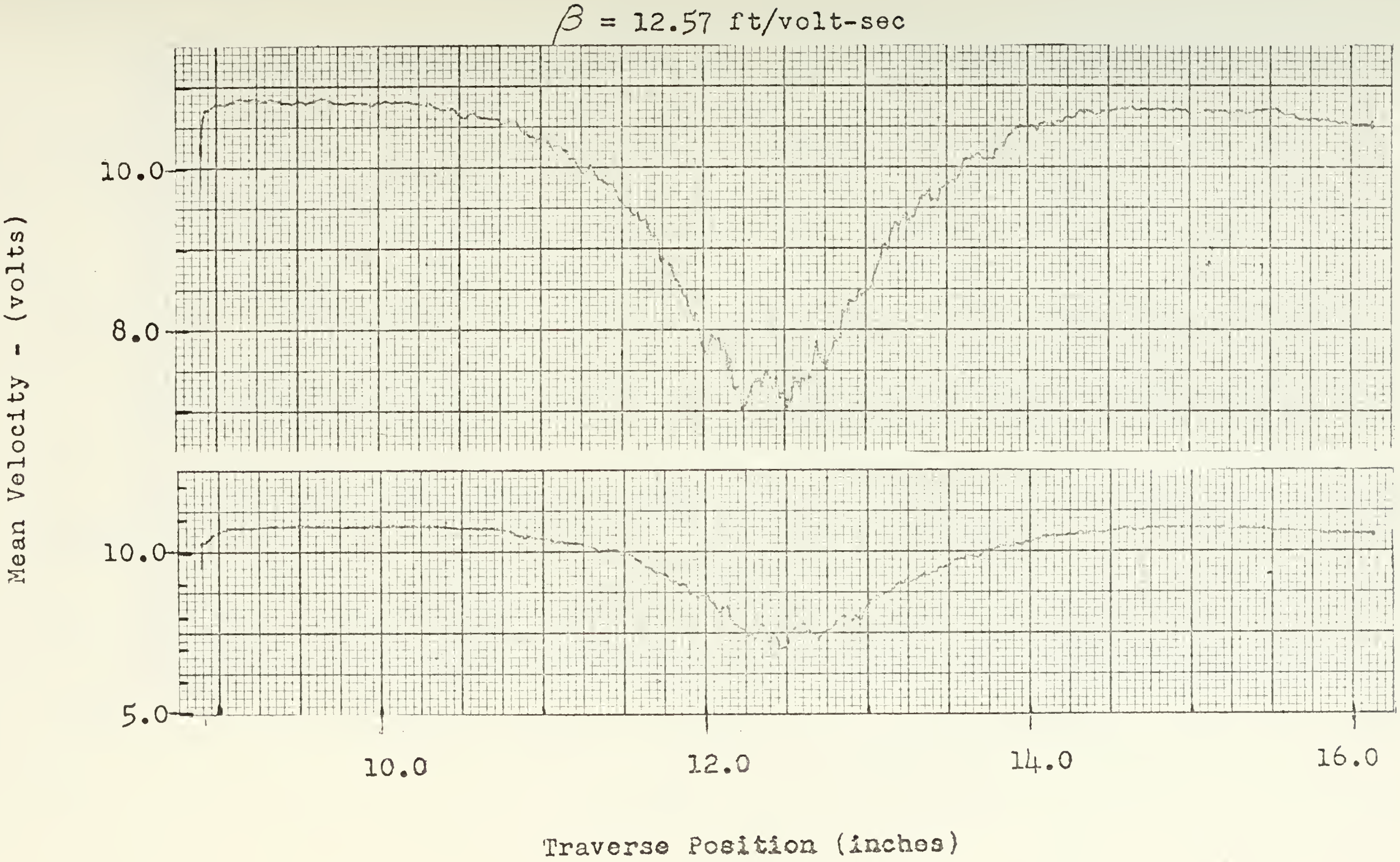


FIGURE 1
Station 1 Normal Wire Mean Velocity

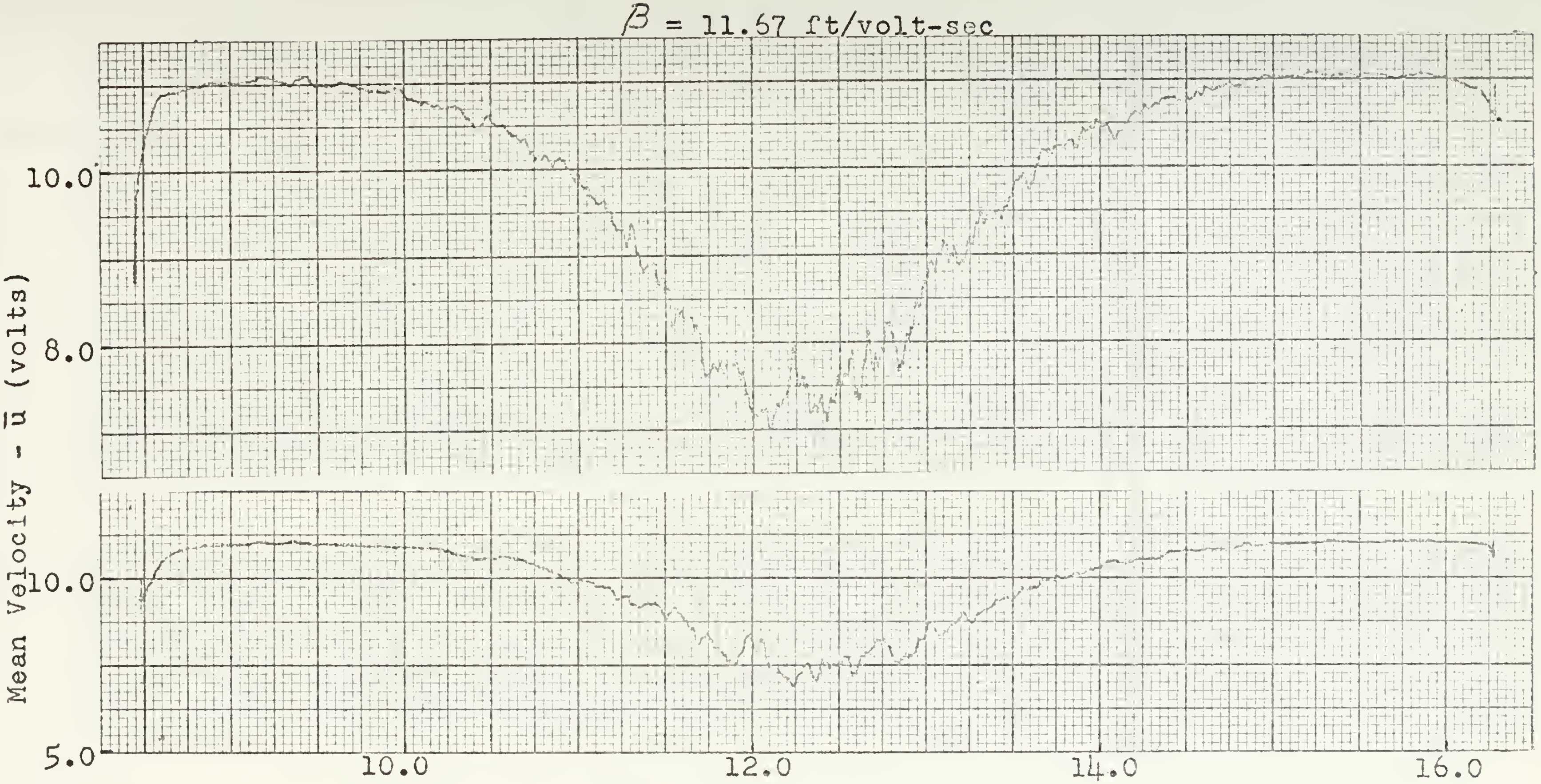


FIGURE 2

Station 2 Normal Wire Mean Velocity

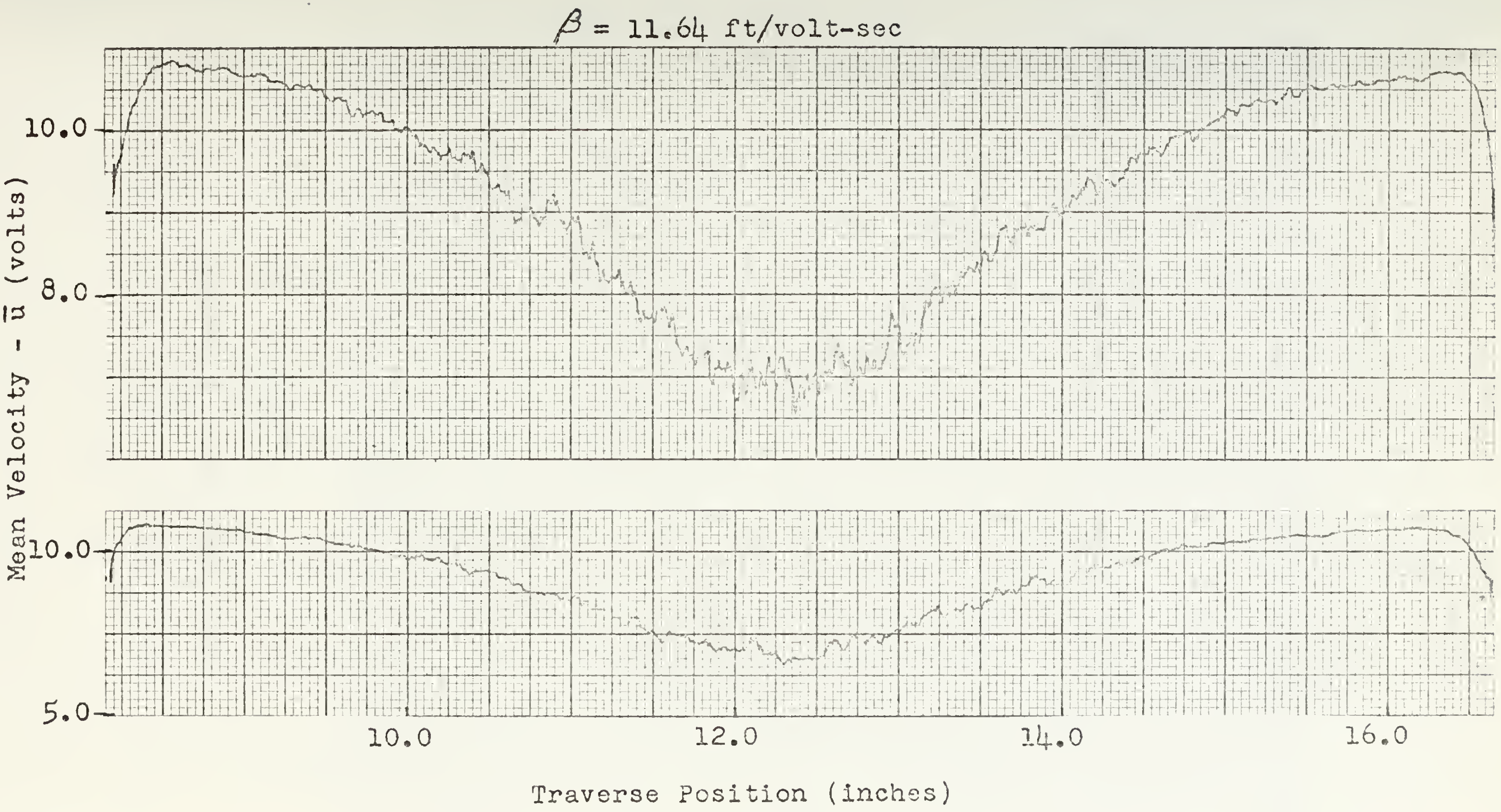


FIGURE 3

Station 3 Normal Wire Mean Velocity

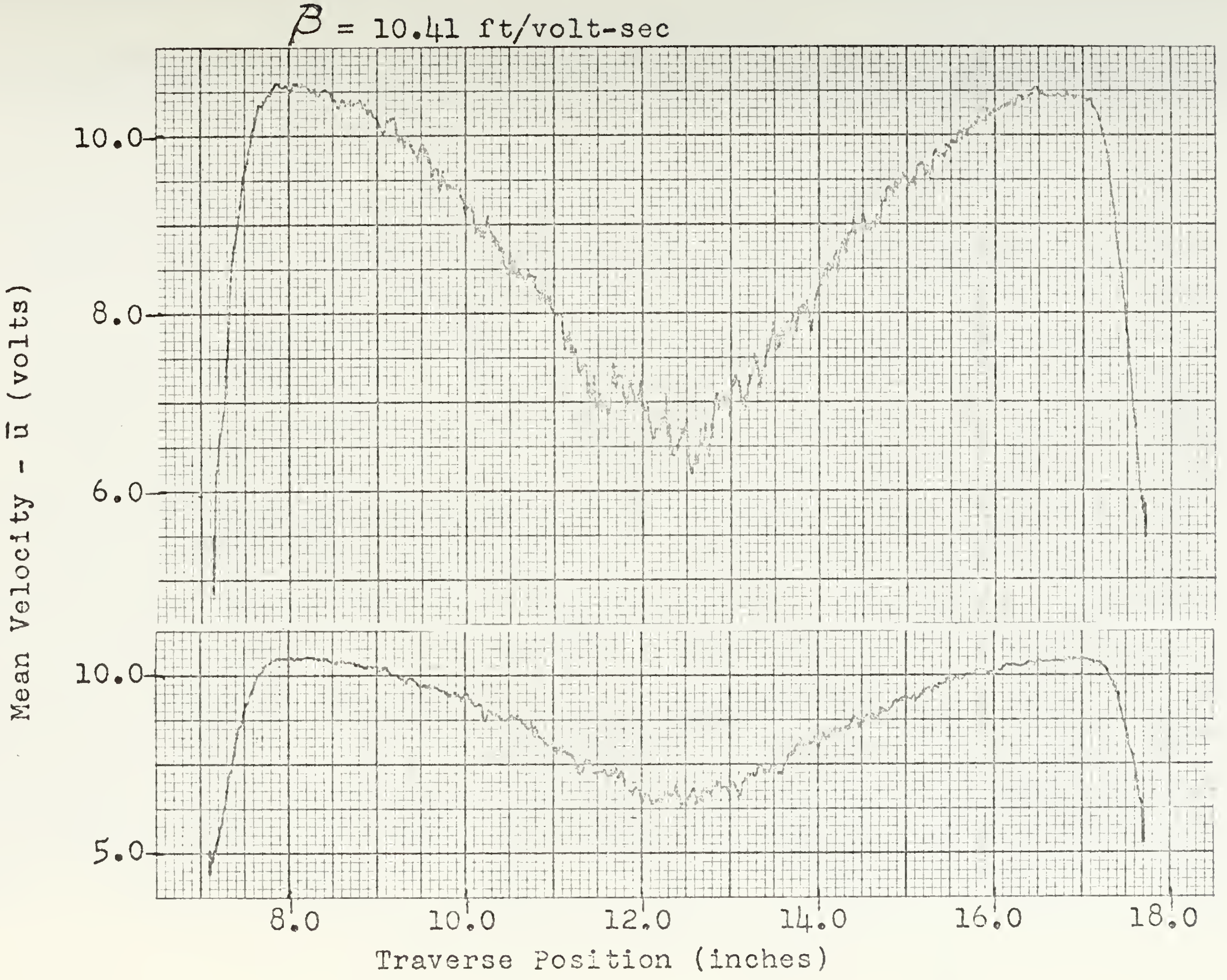


FIGURE 4

Station 4 Normal Wire Mean Velocity

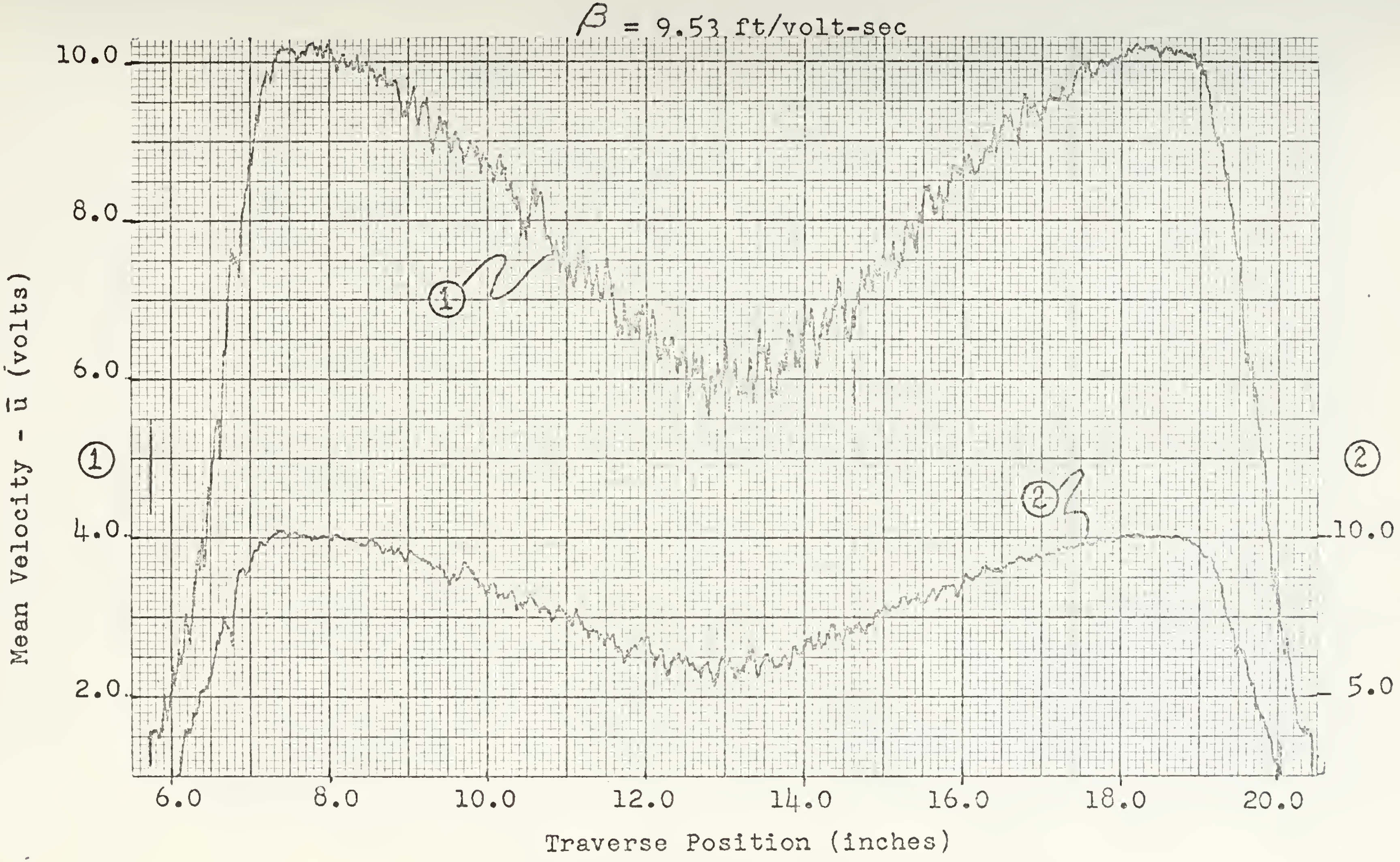


FIGURE 5
Station 5 Normal Wire Mean Velocity

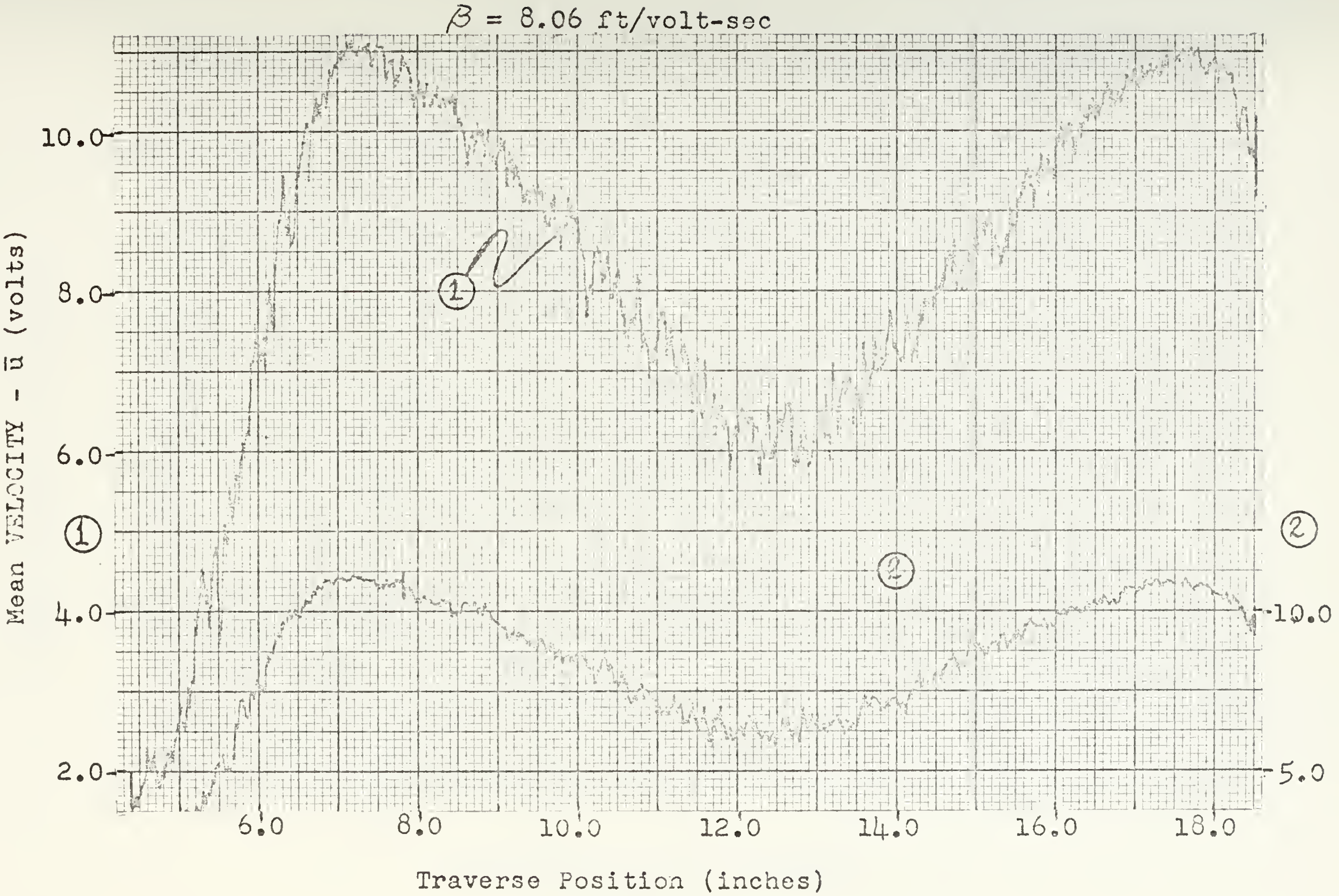


FIGURE 6
Station 6 Normal Wire Mean Velocity

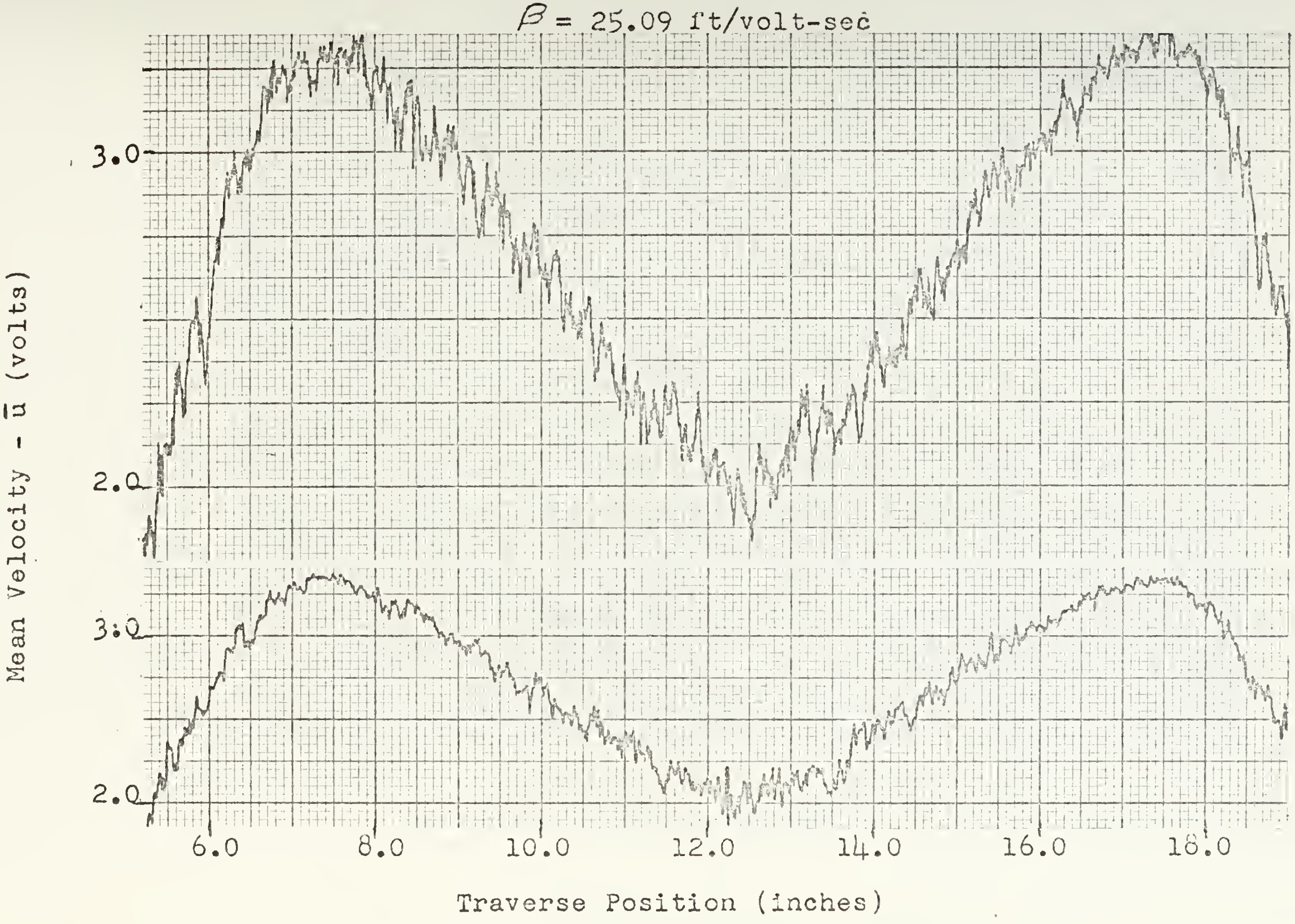


FIGURE 7
Station 7 Normal Wire Mean Velocity

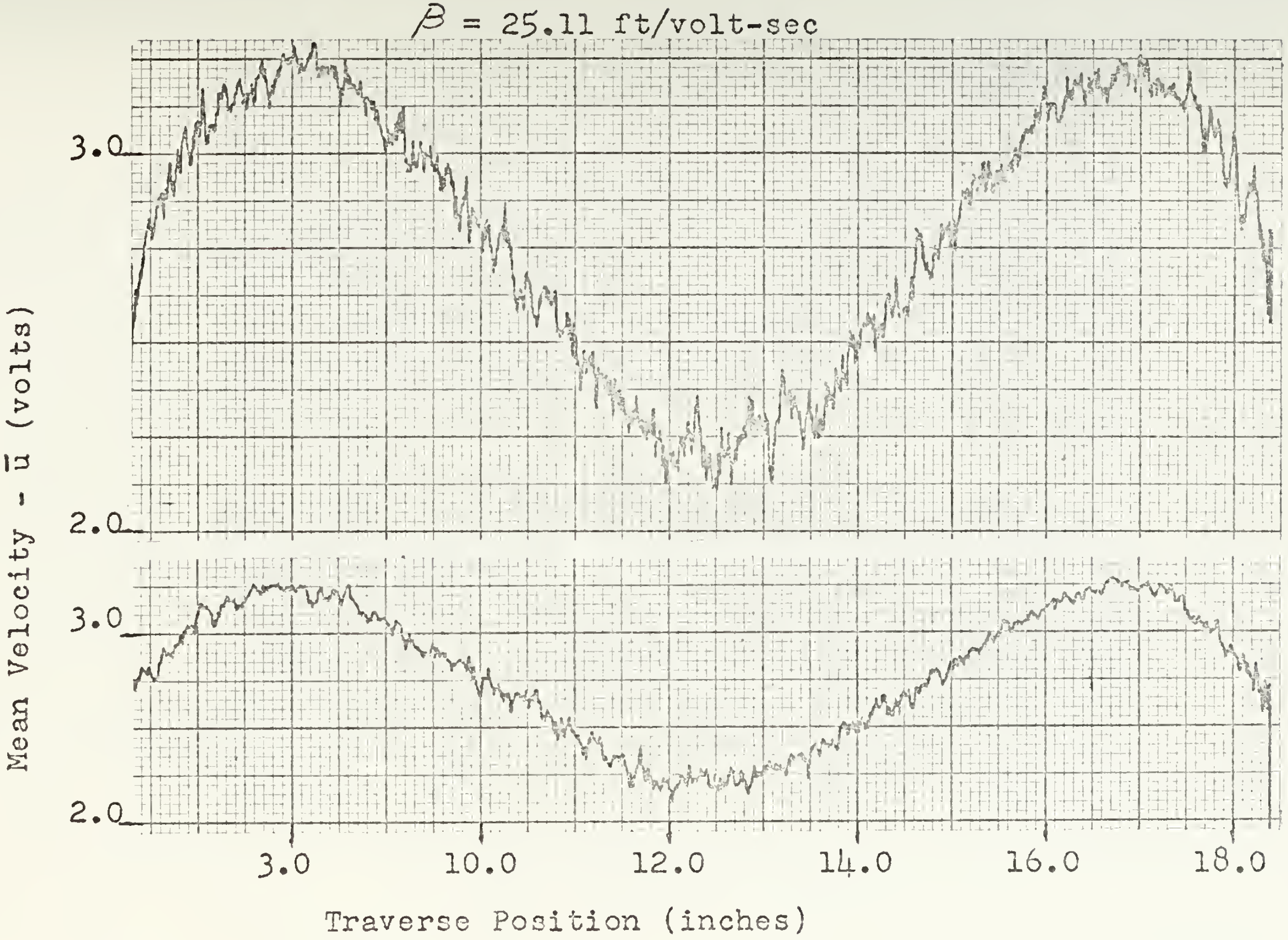


FIGURE 8

Station 8 Normal Wire Mean Velocity

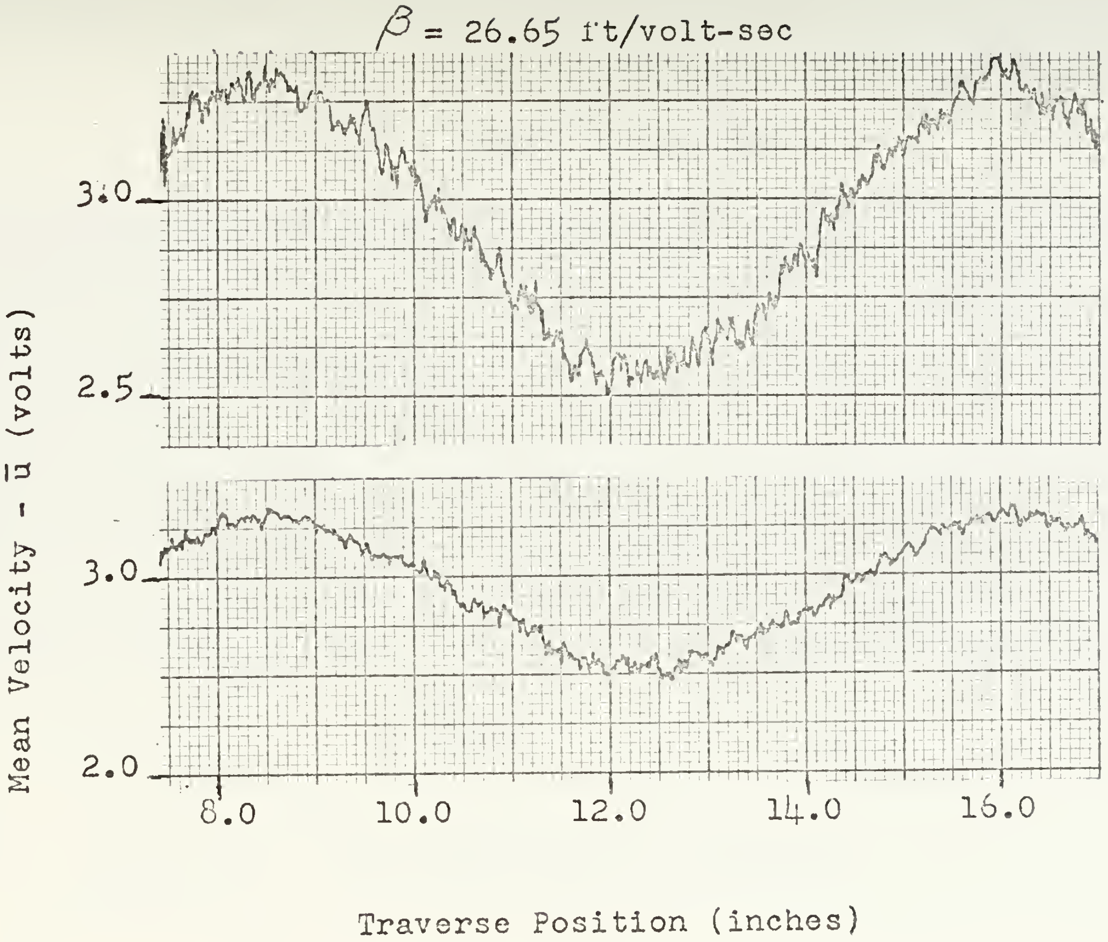


FIGURE 9
Station 9 Normal Wire Mean Velocity

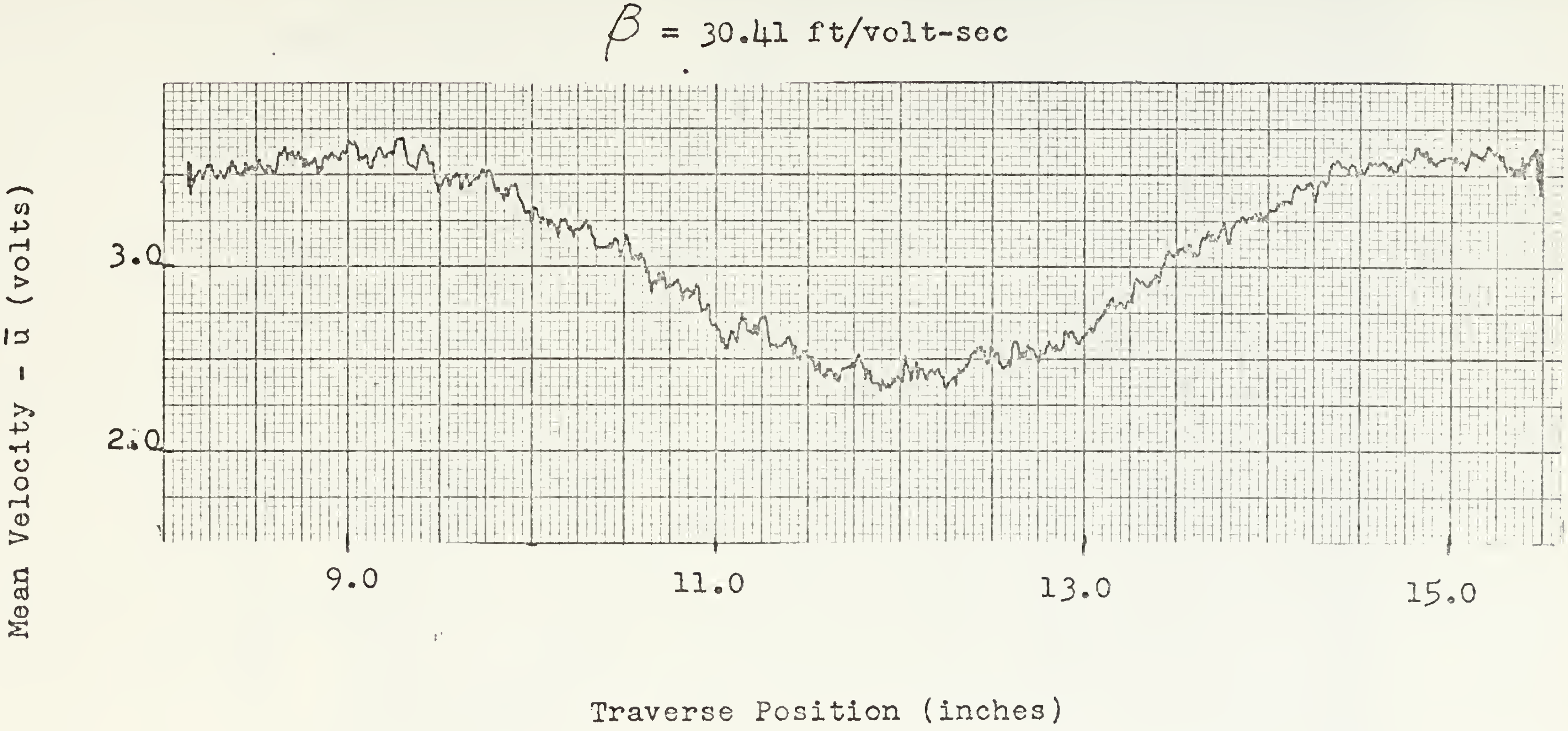


FIGURE 10
Station 10 Normal Wire Mean Velocity

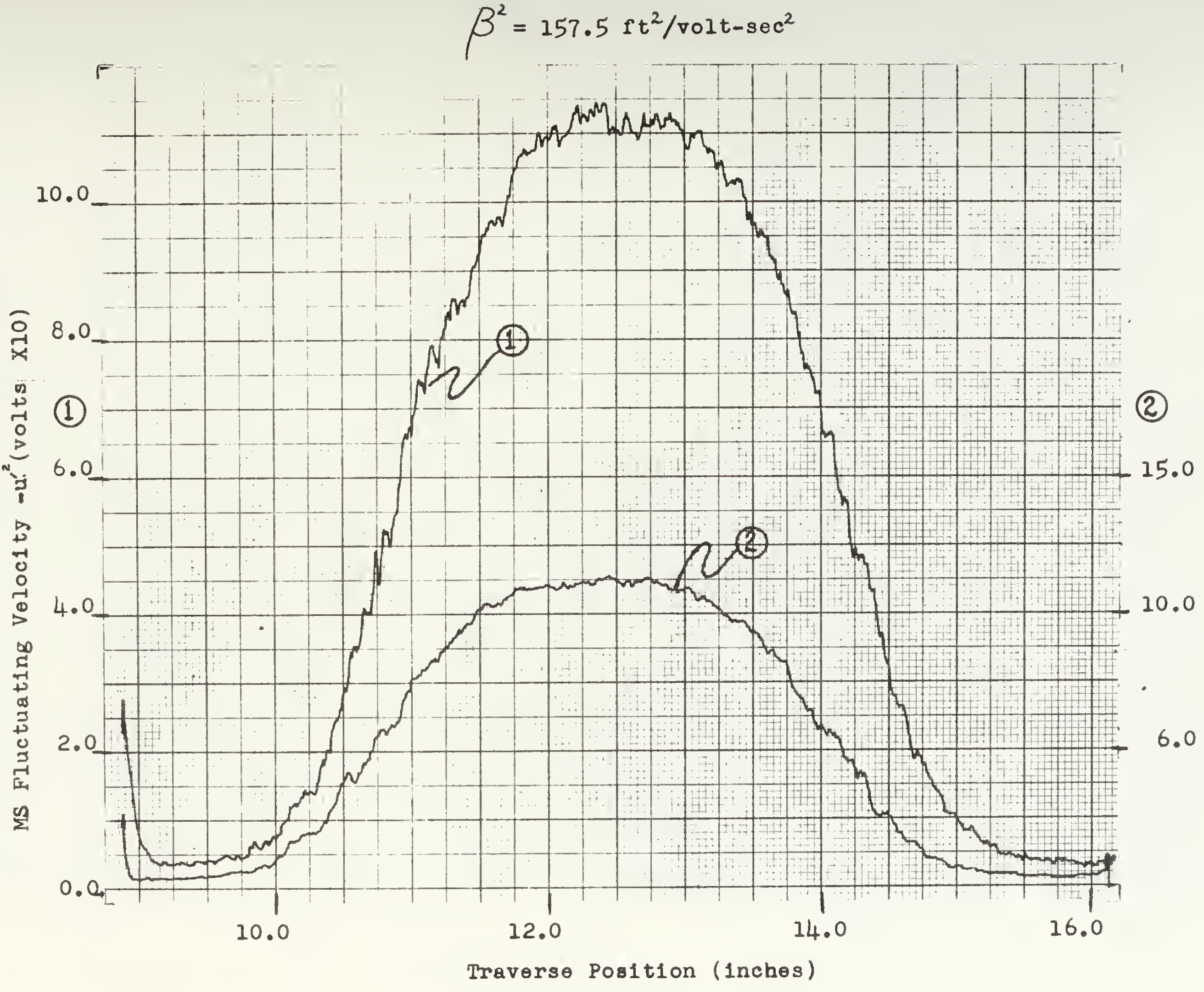


FIGURE 11
Station 1 MS Normal Wire Fluctuating Velocity

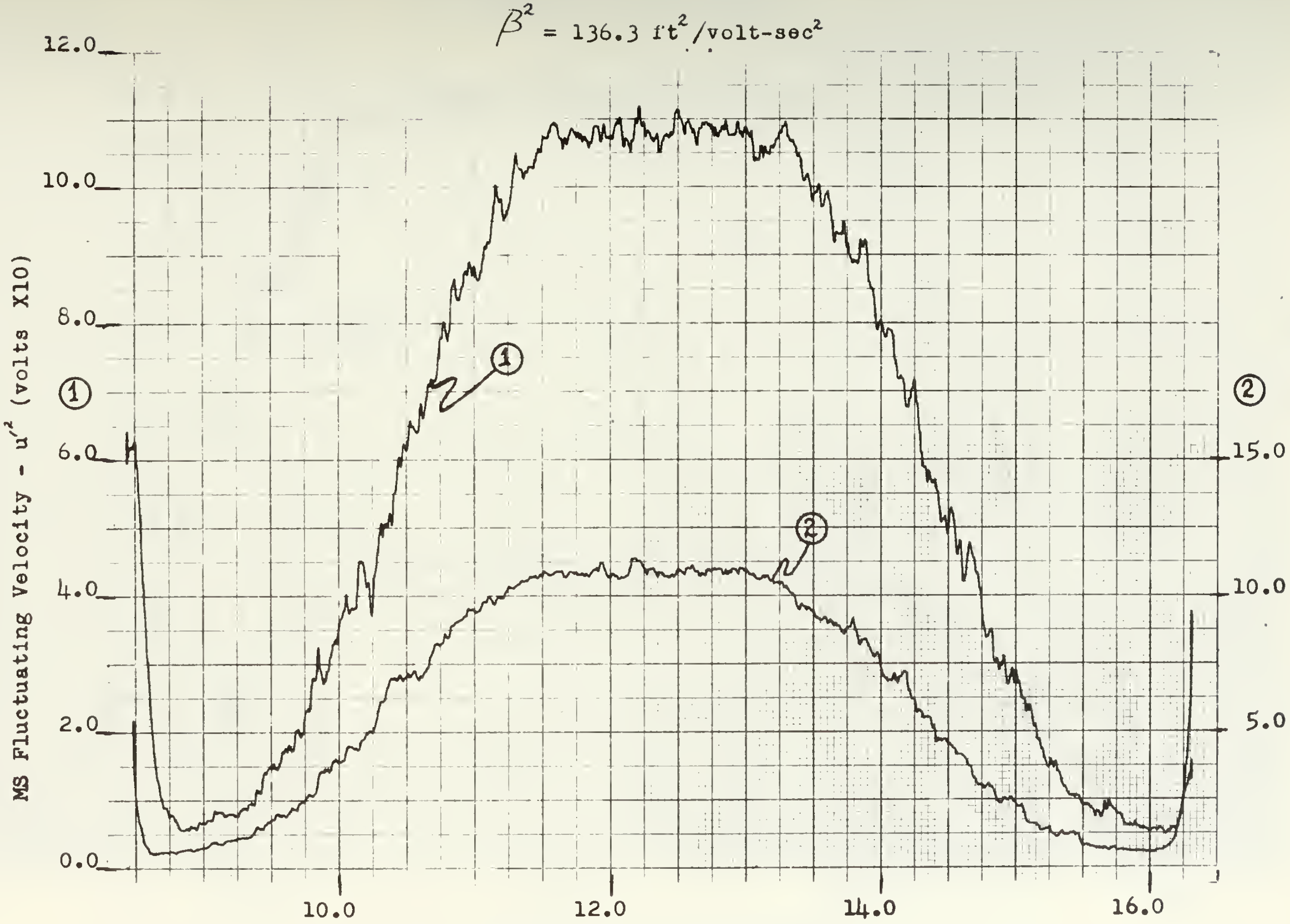


FIGURE 12

Station 2 MS Normal Wire Fluctuating Velocity

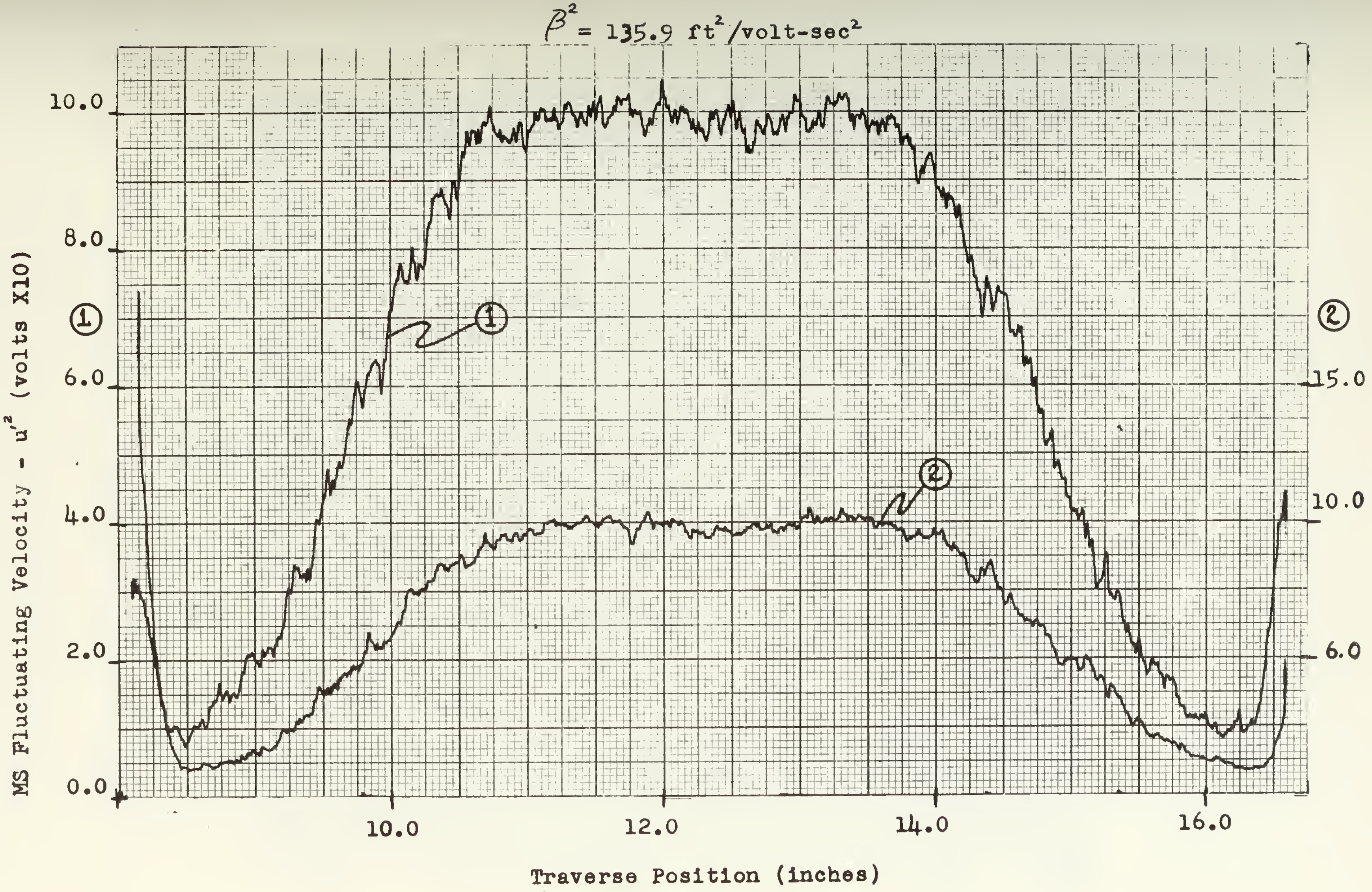


FIGURE 13
Station 3 MS Normal Wire Fluctuating Velocity

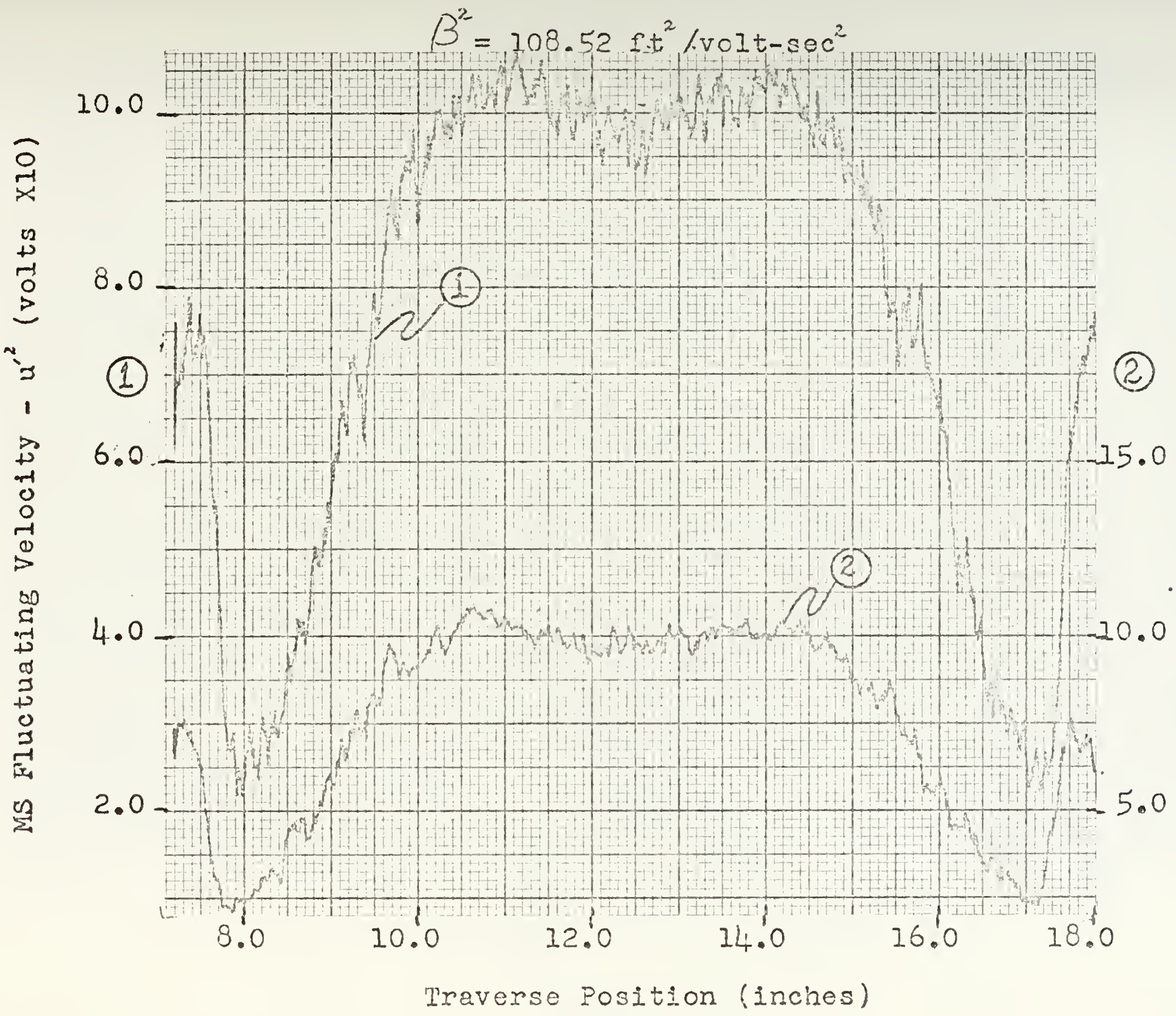


FIGURE 14
Station 4 MS Normal Wire Fluctuating Velocity

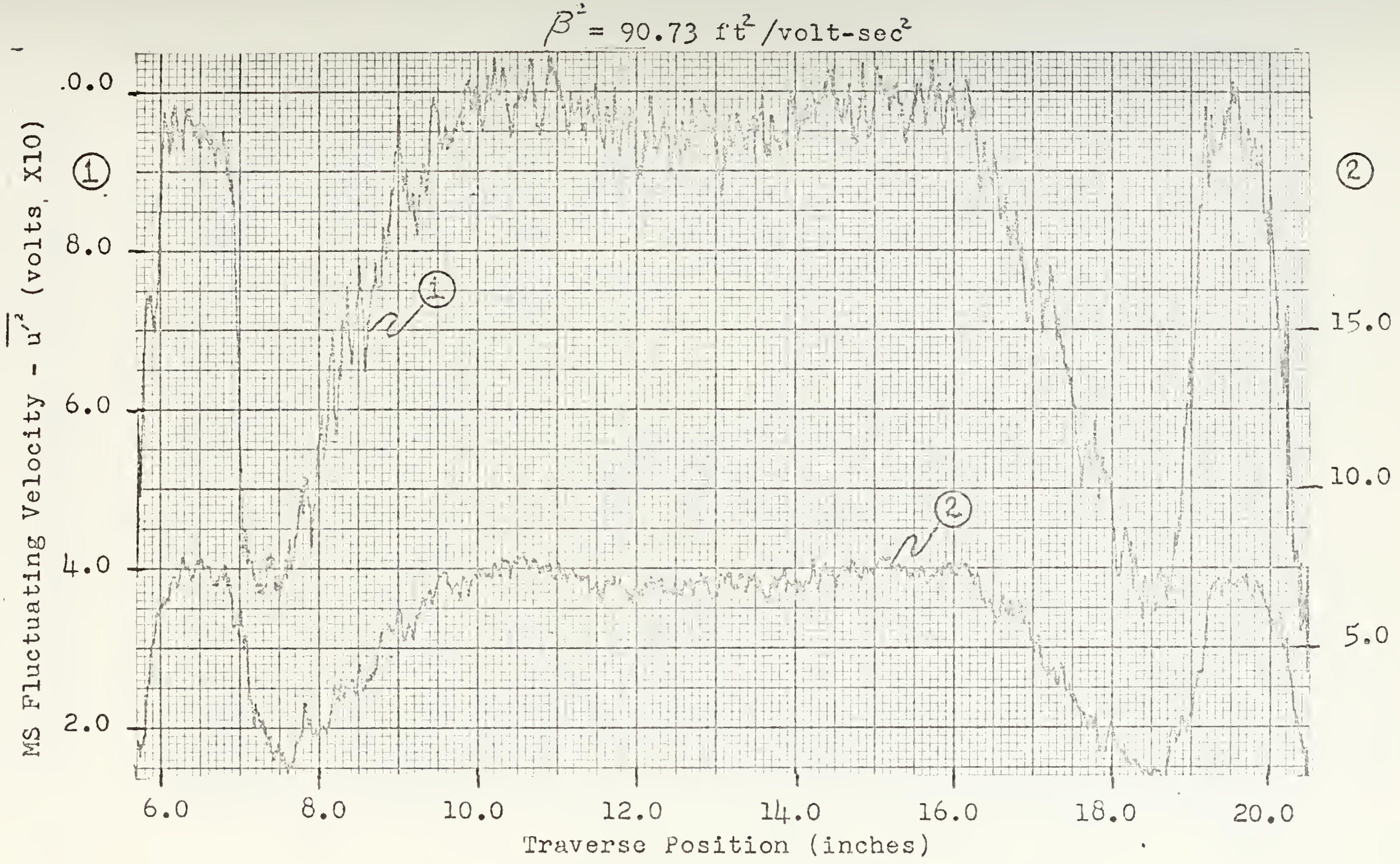


FIGURE 15
Station 5 MS Normal Wire Fluctuating Velocity

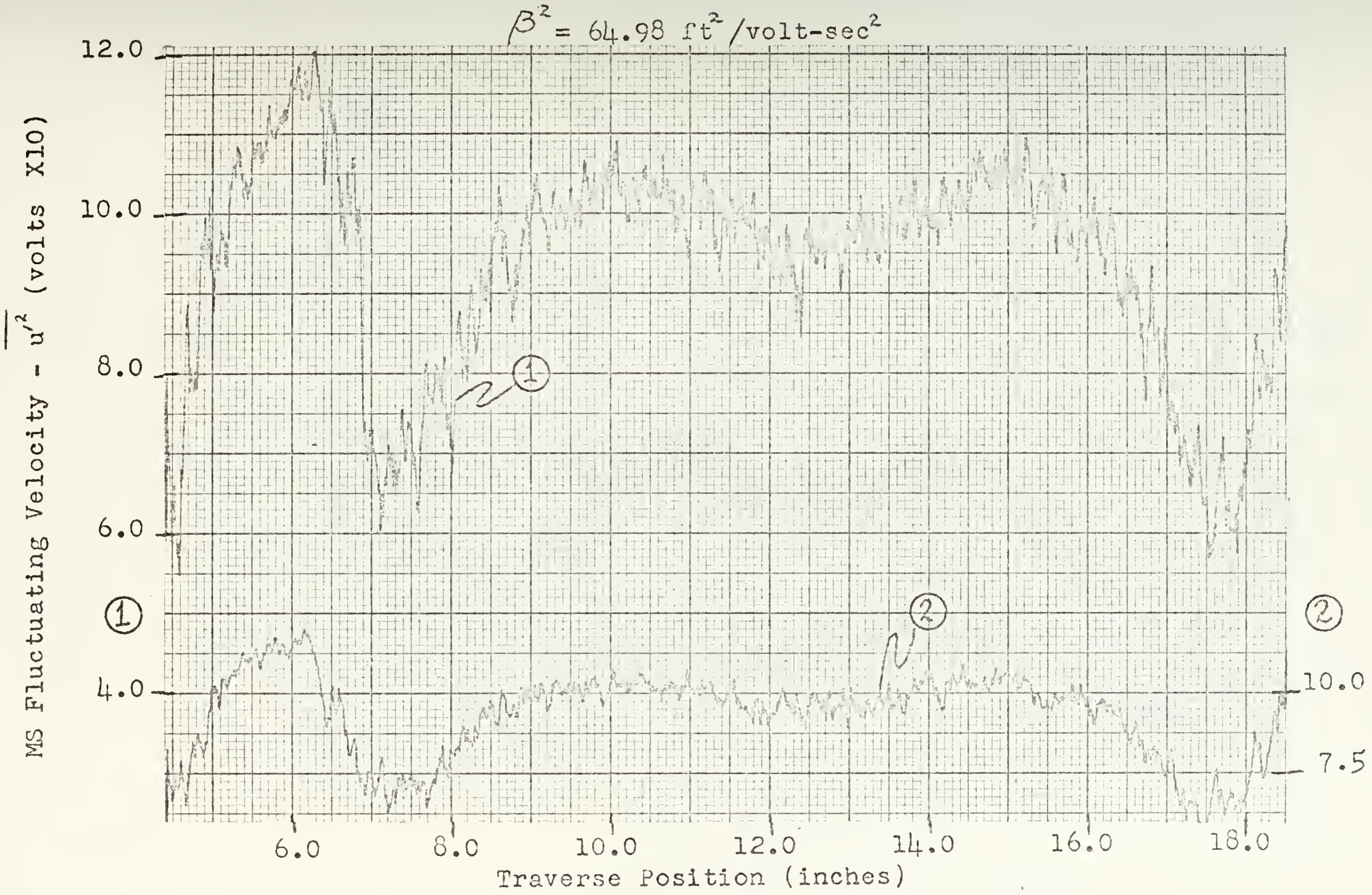


FIGURE 16
Station 6 MS Normal Wire Fluctuating Velocity

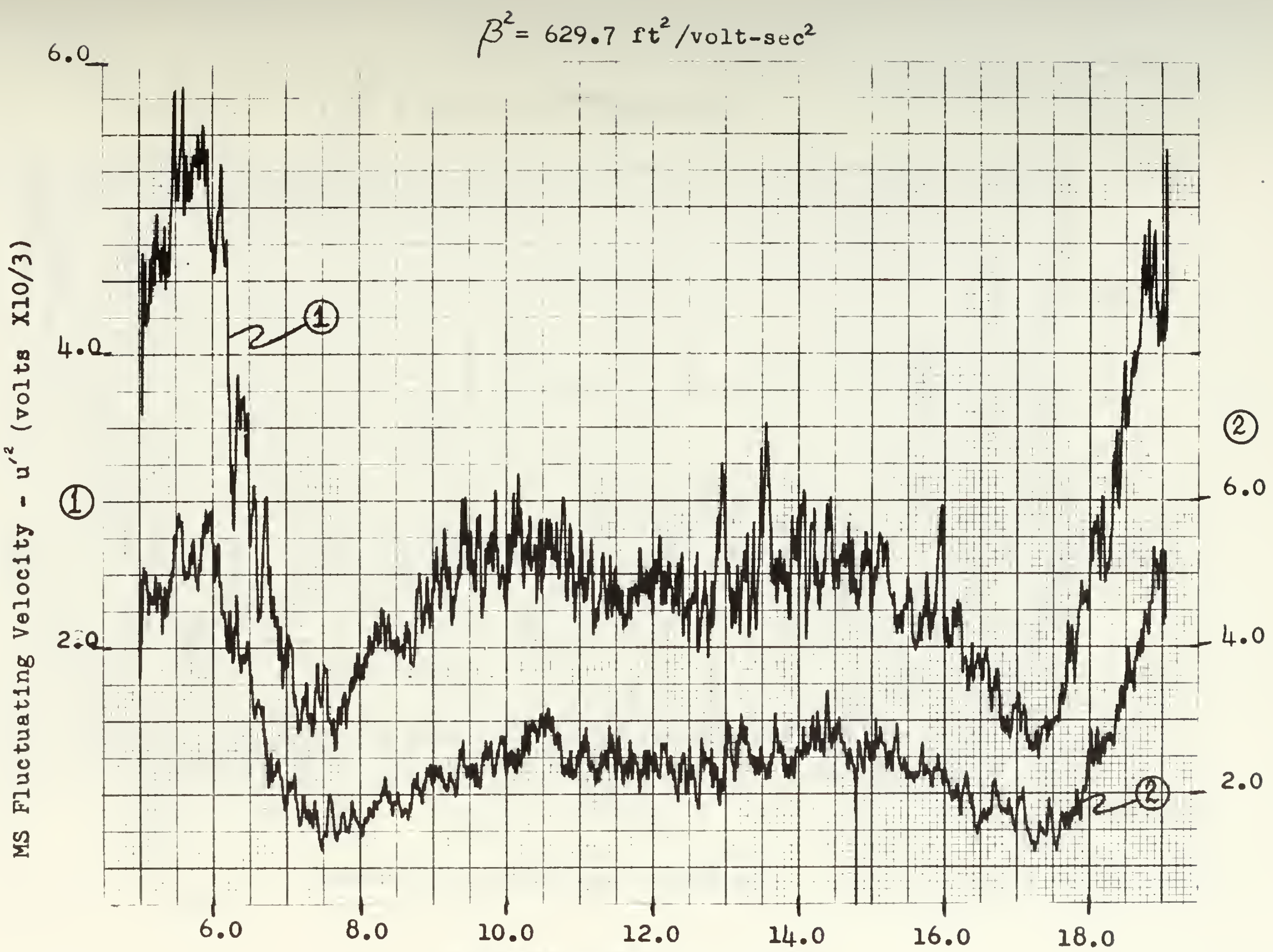


FIGURE 17
Station 7 MS Normal Wire Fluctuating Velocity

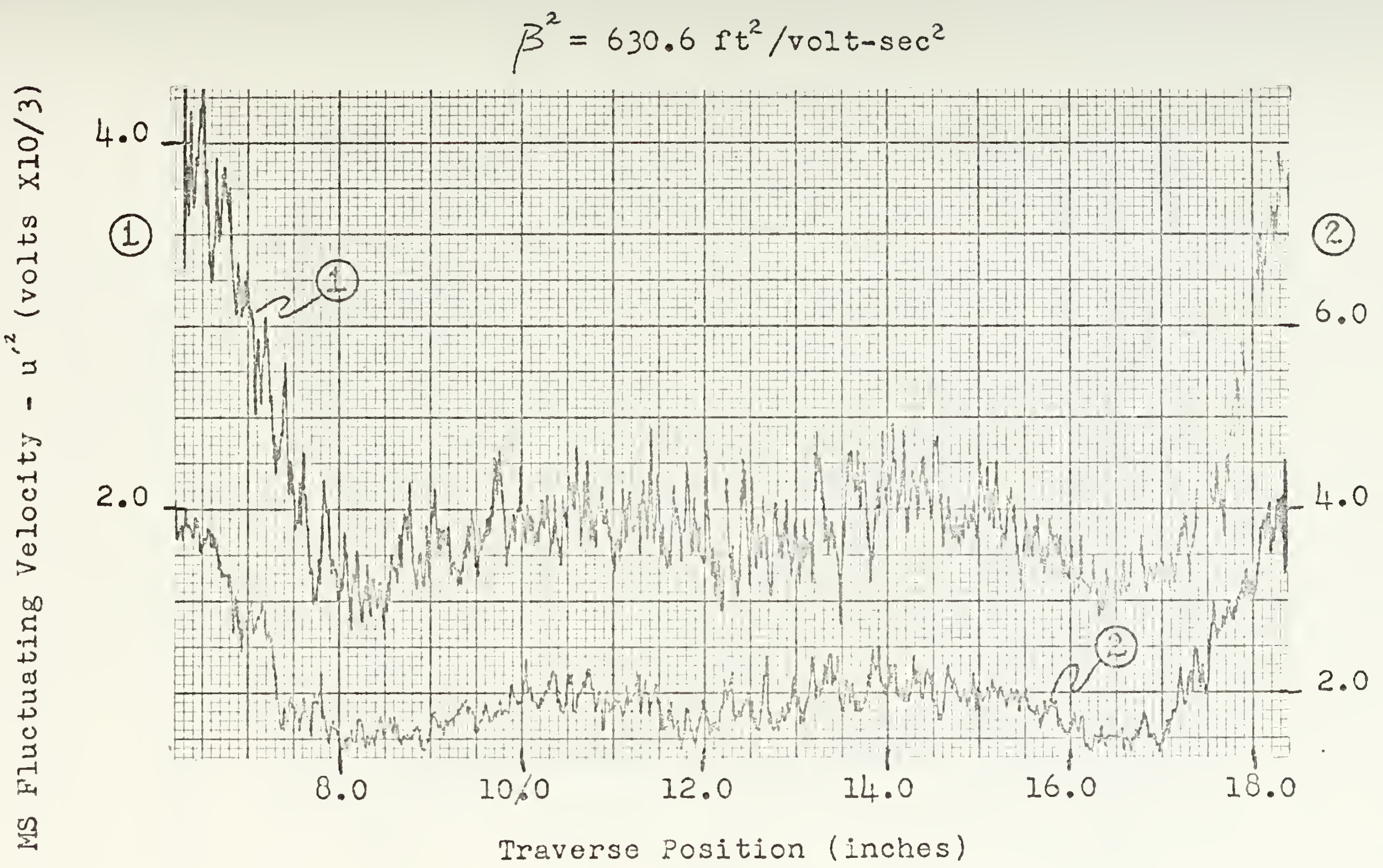


FIGURE 18
Station 8 MS Normal Wire Fluctuating Velocity

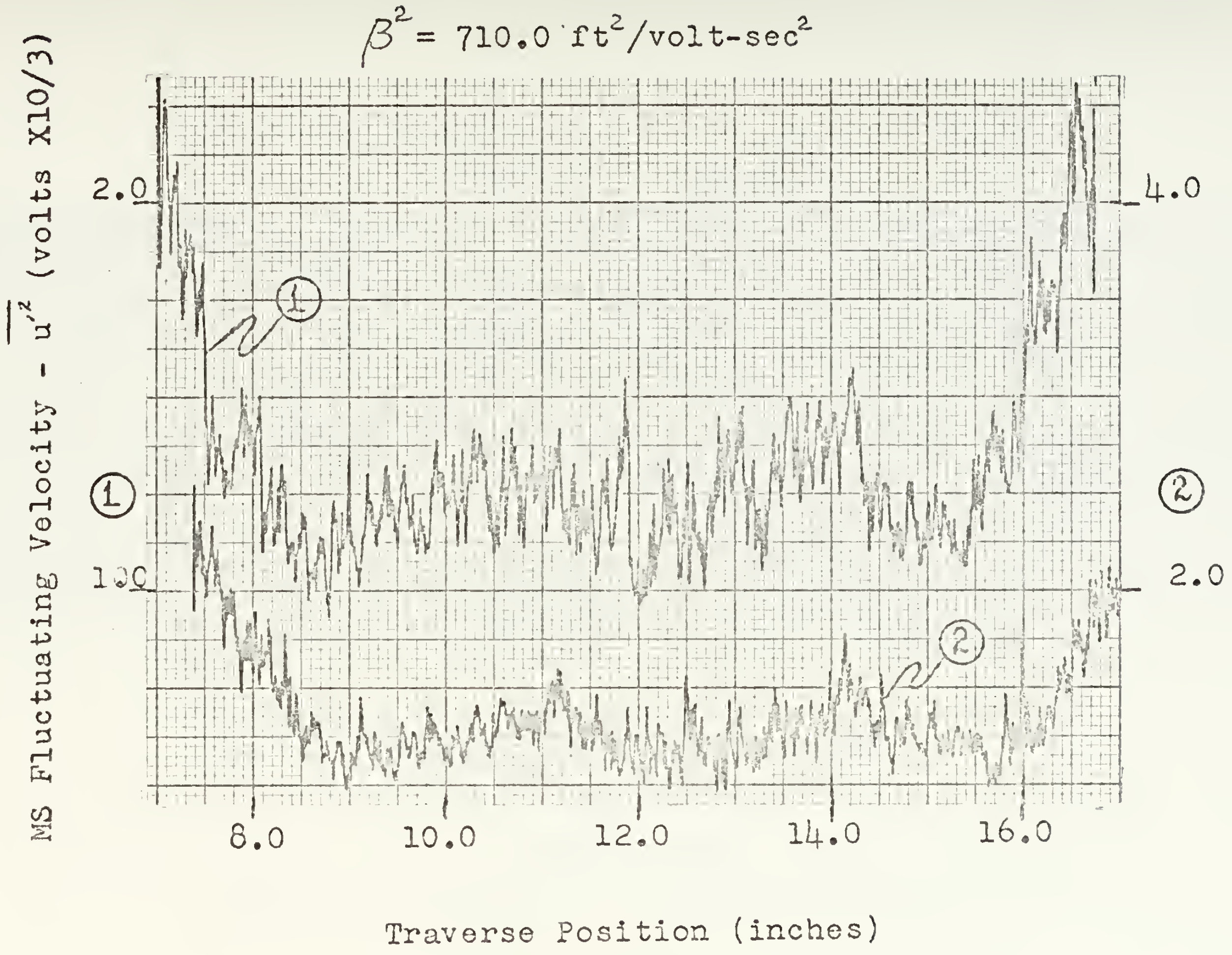


FIGURE 19
Station 9 MS normal Wire Fluctuating Velocity

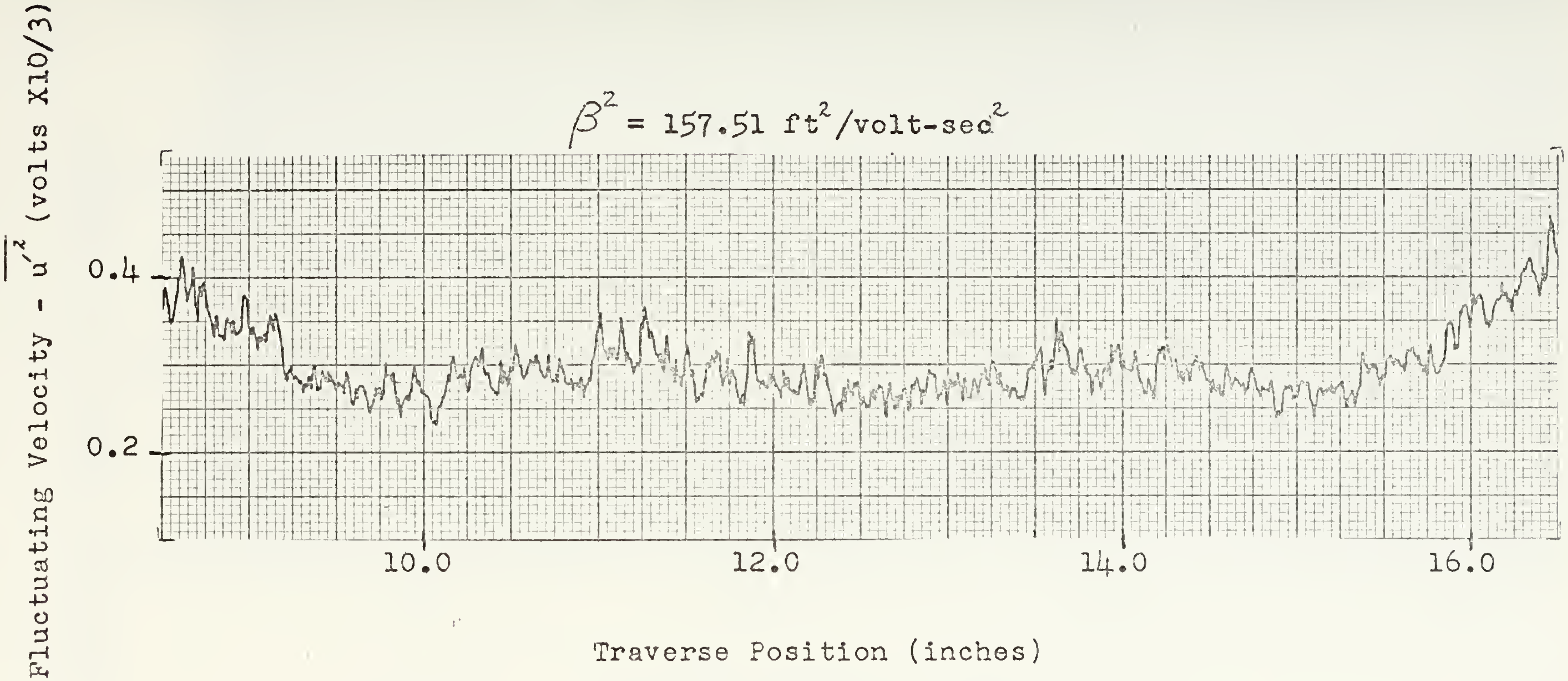


FIGURE 20
Station 10 MS Normal Wire Fluctuating Velocity

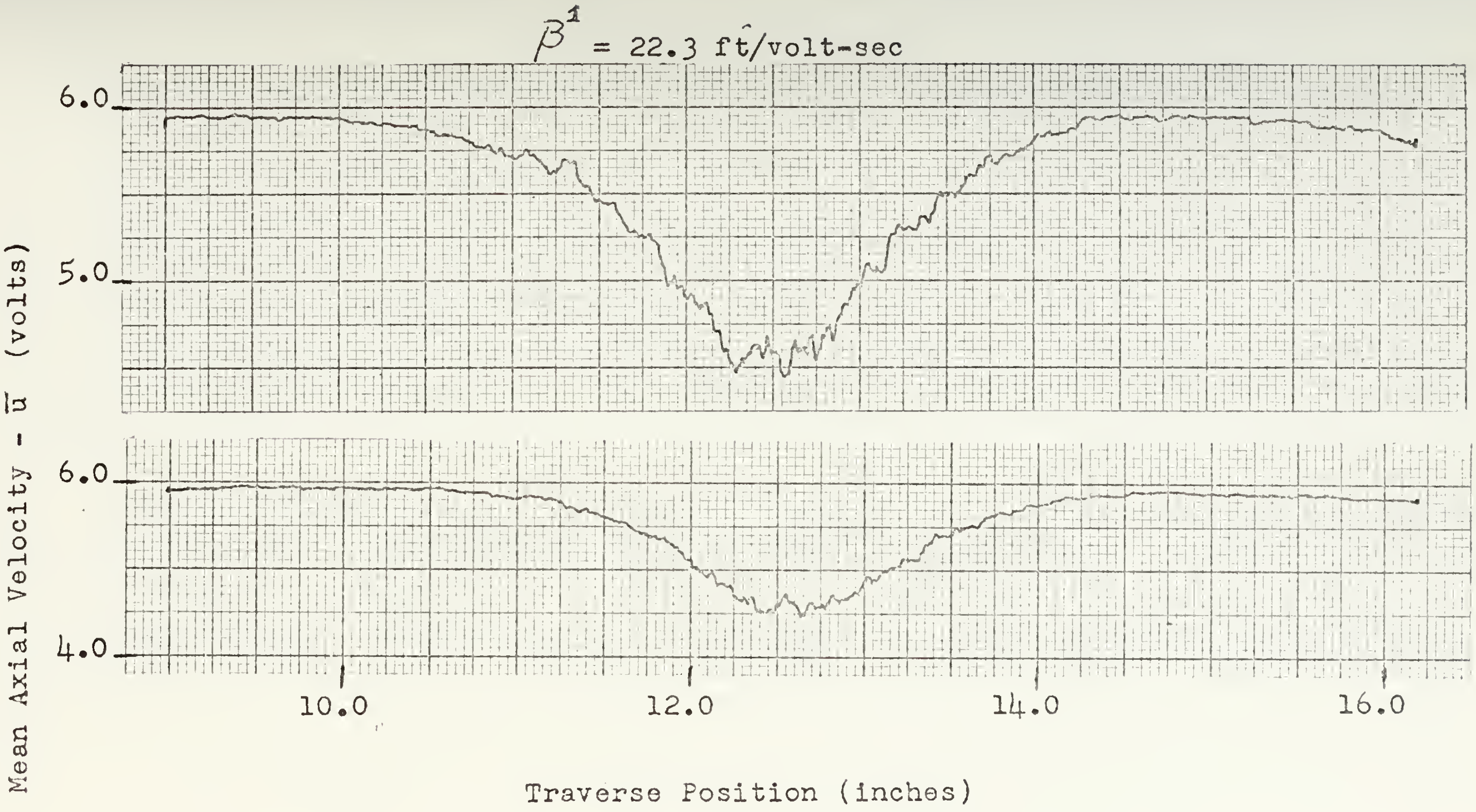


FIGURE 21
Station 1 X-Array Mean Axial Velocity

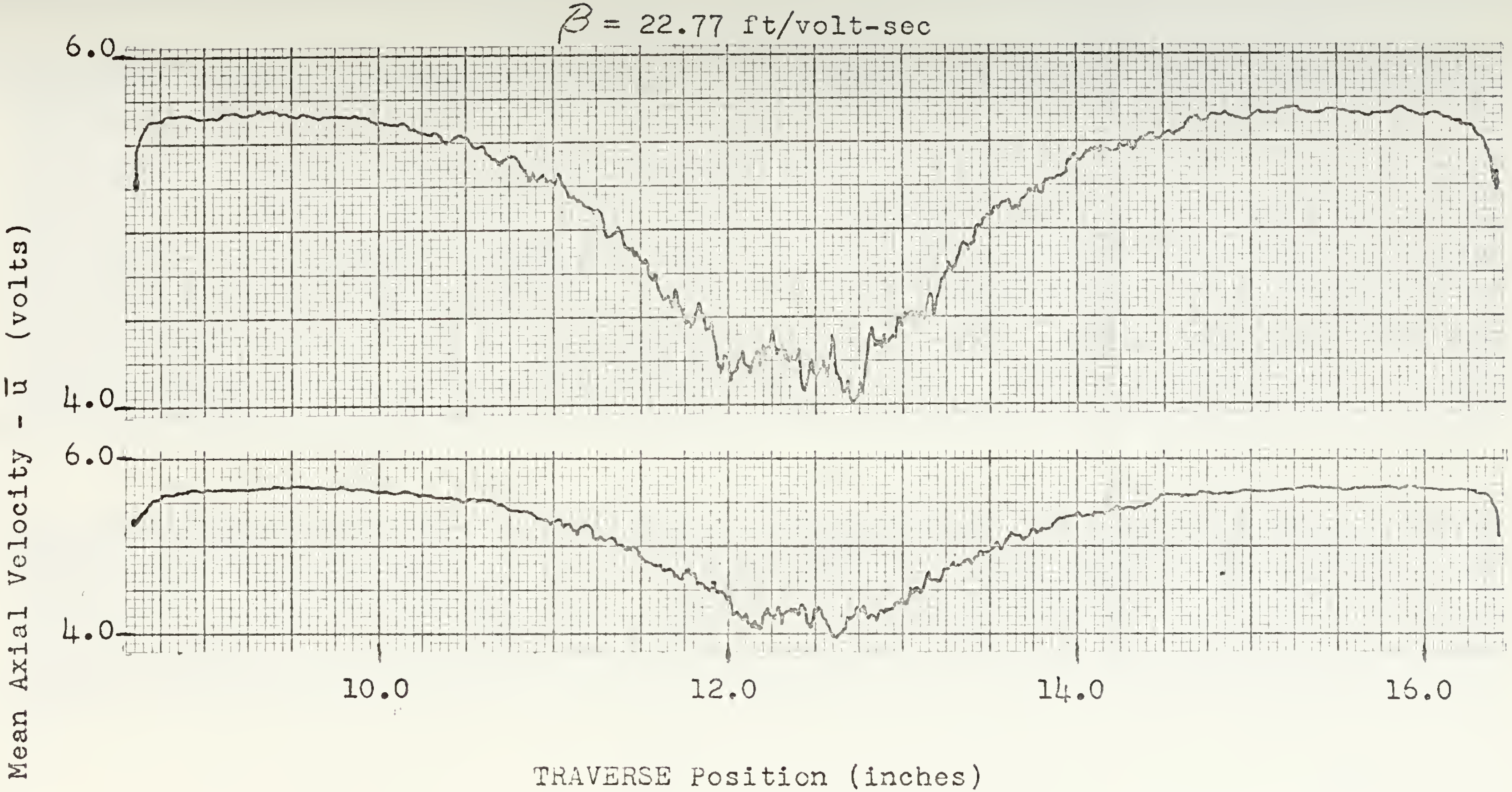


FIGURE 22
Station 2 X-Array Mean Axial Velocity

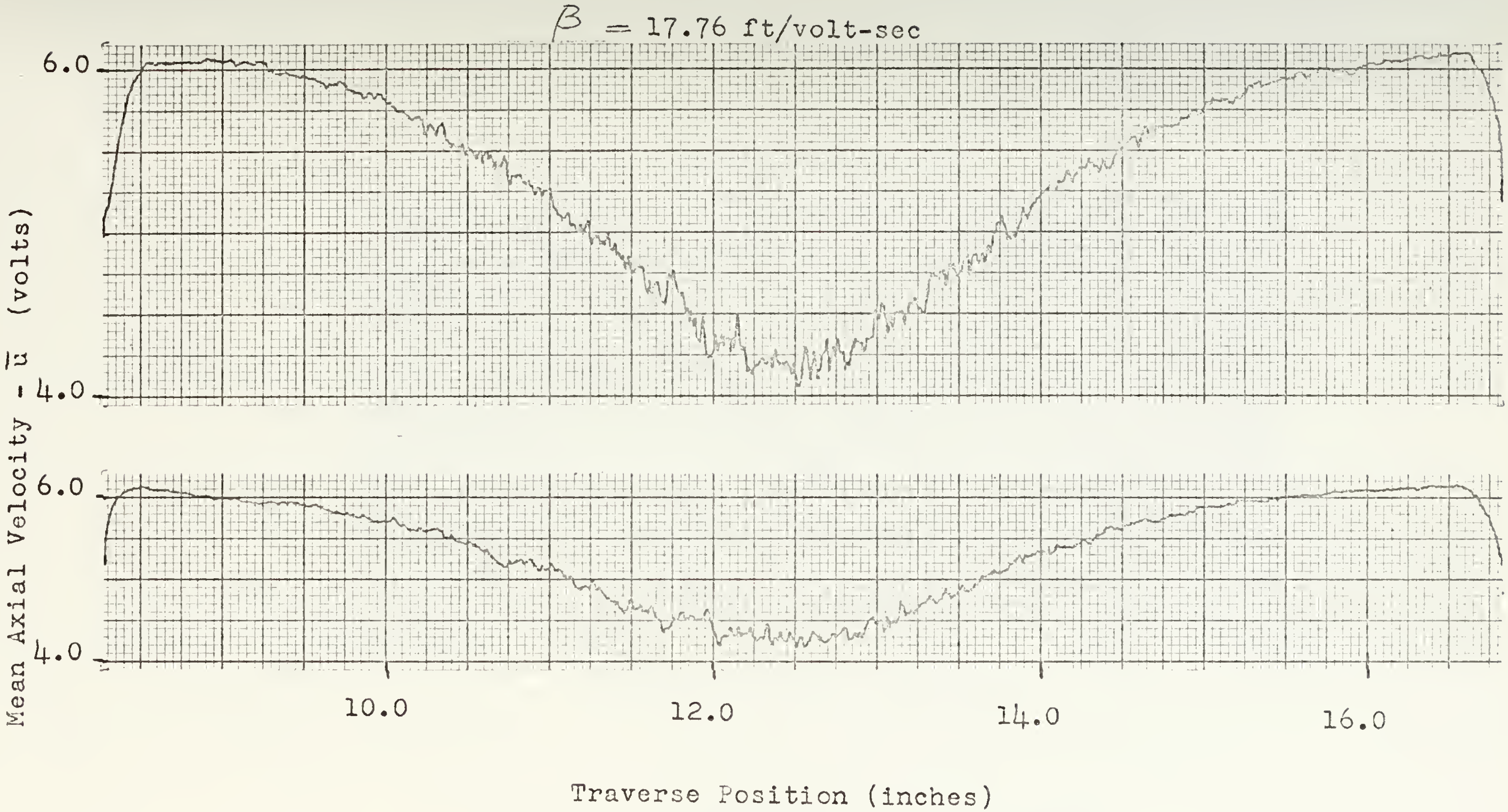


FIGURE 23
Station 3 X-Array Mean Axial Velocity

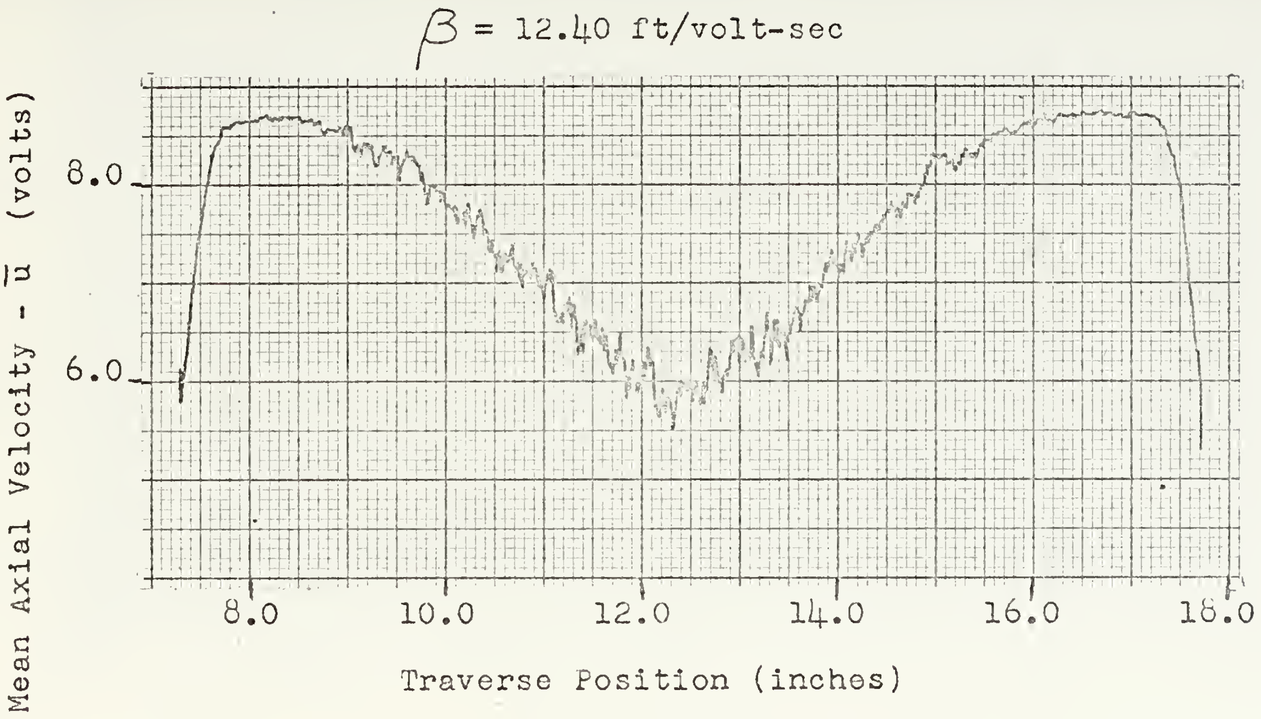


FIGURE 24
Station 4 X-Array Mean Axial Velocity

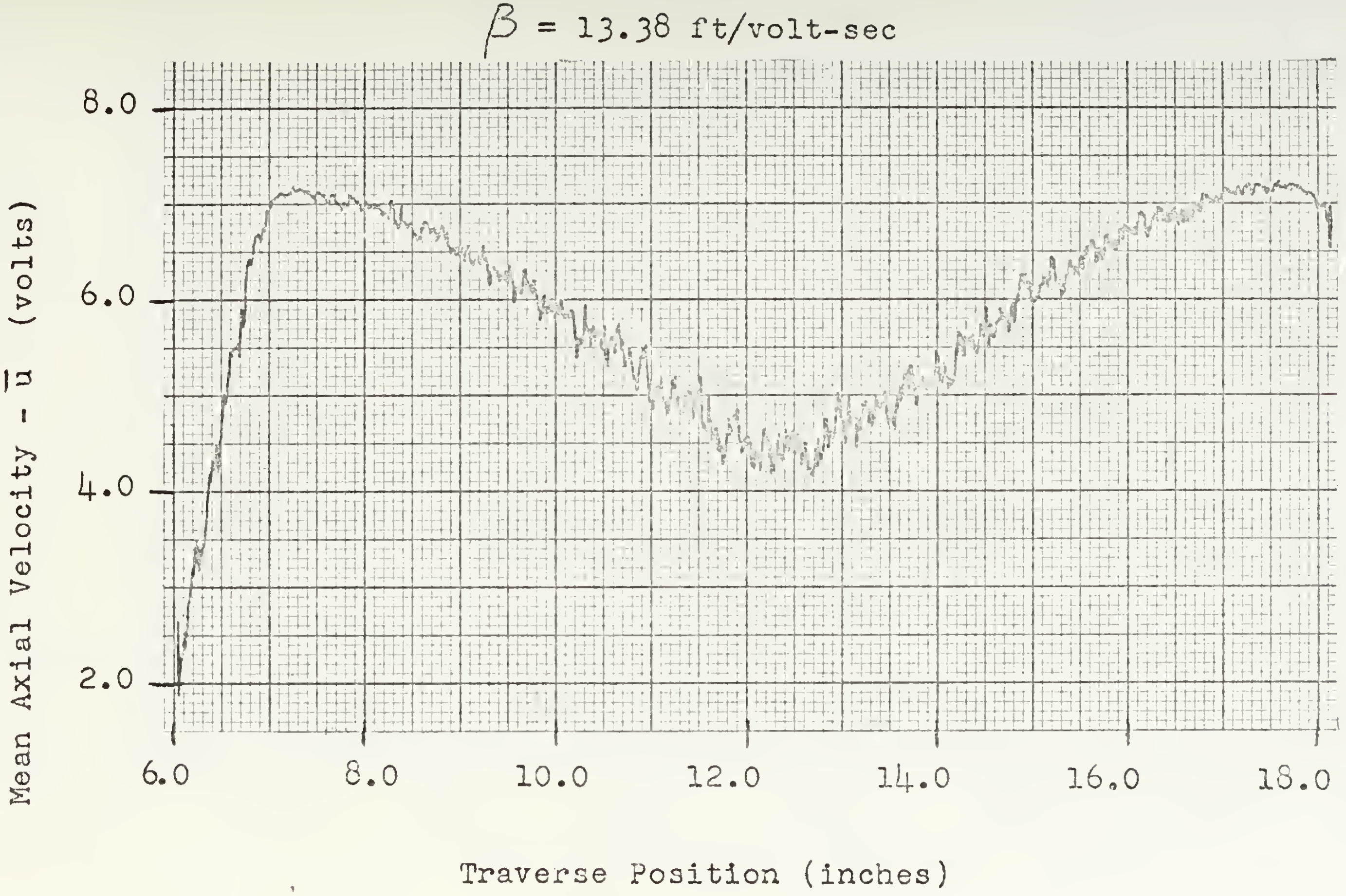


FIGURE 25
Station 5 X-Array Mean Axial Velocity

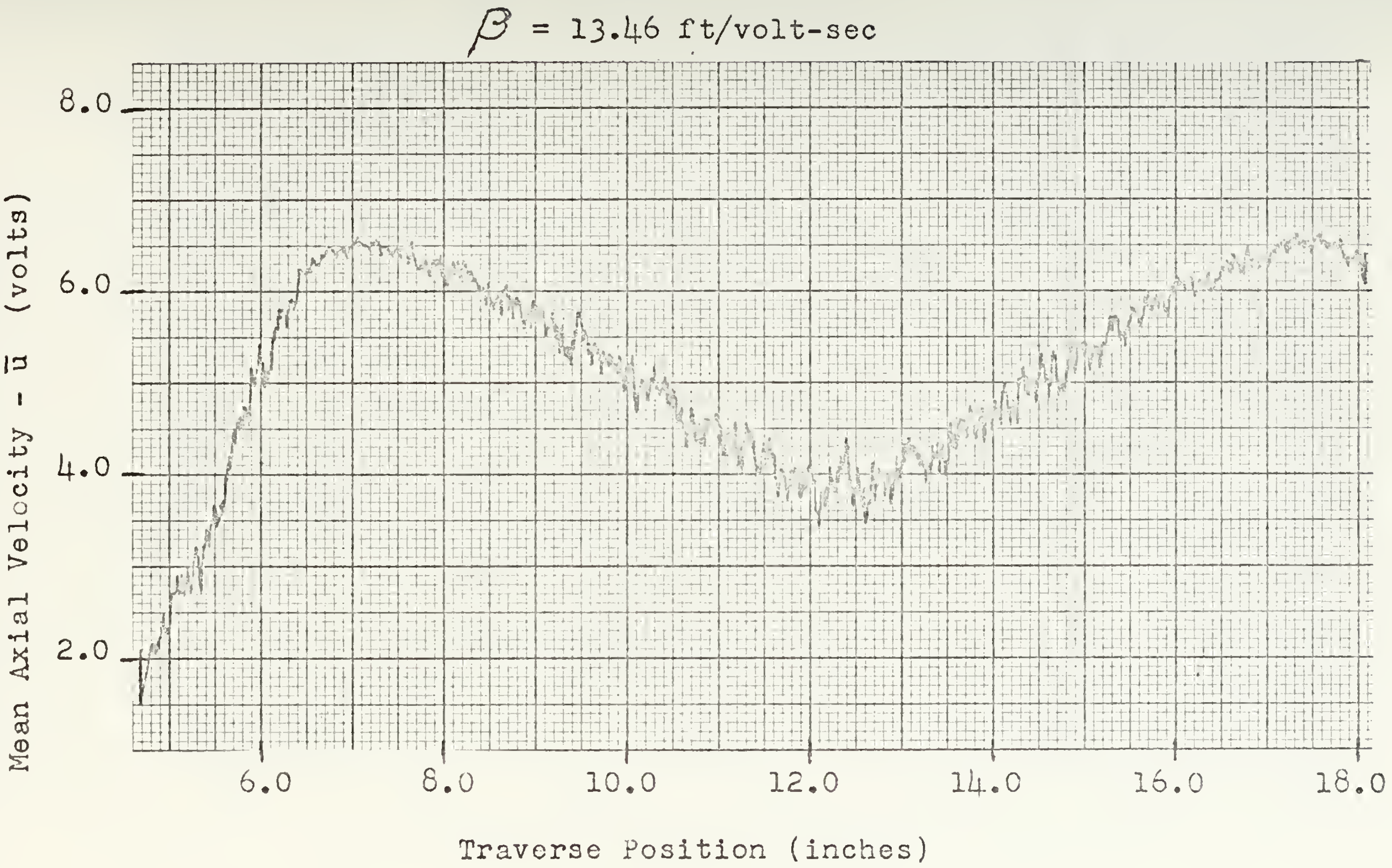


FIGURE 26
Station 6 X-Array Mean Axial Velocity

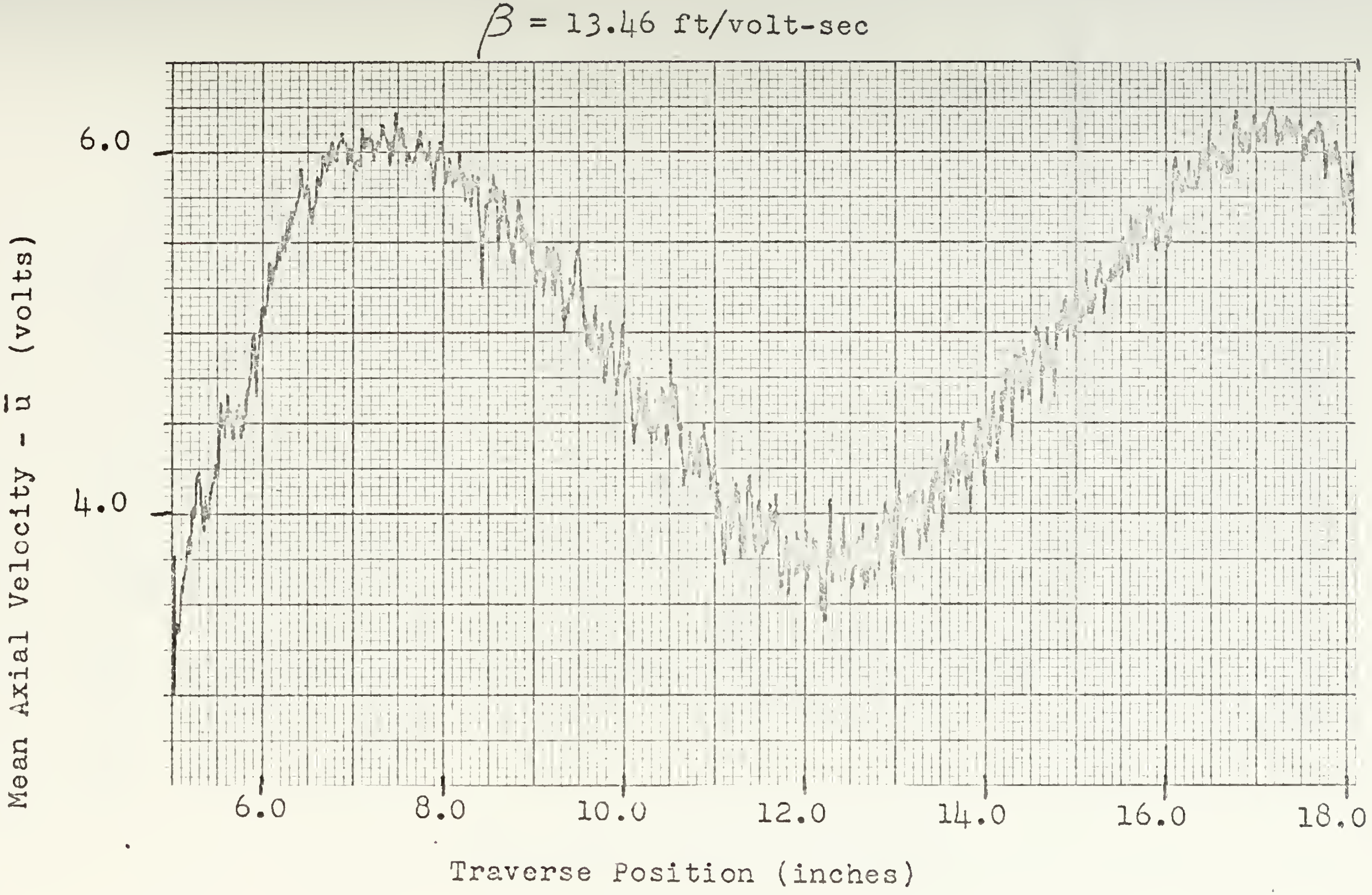


FIGURE 27
Station 7 X-Array Mean Axial Velocity

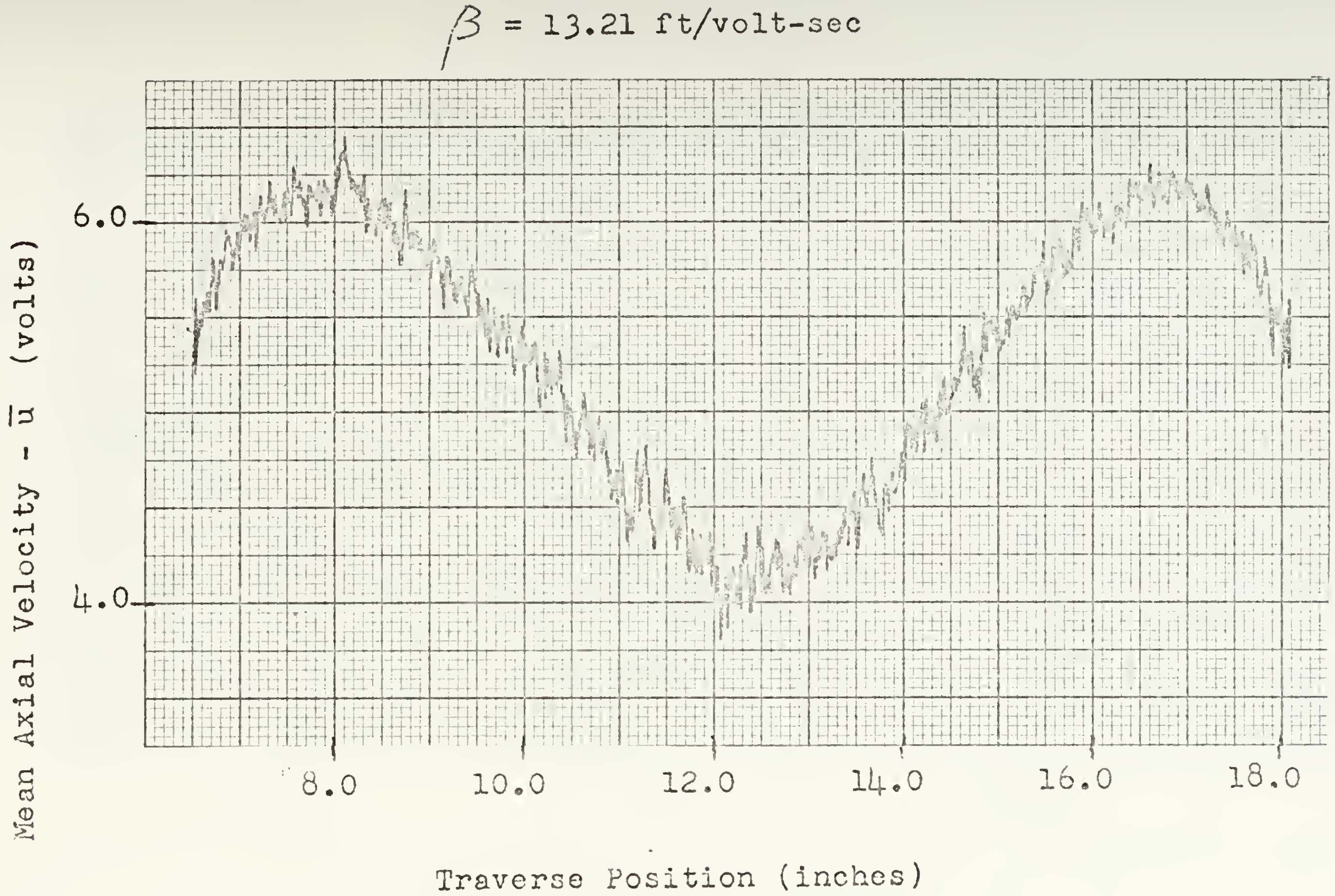


FIGURE 28
Station 8 X-Array Mean Axial Velocity

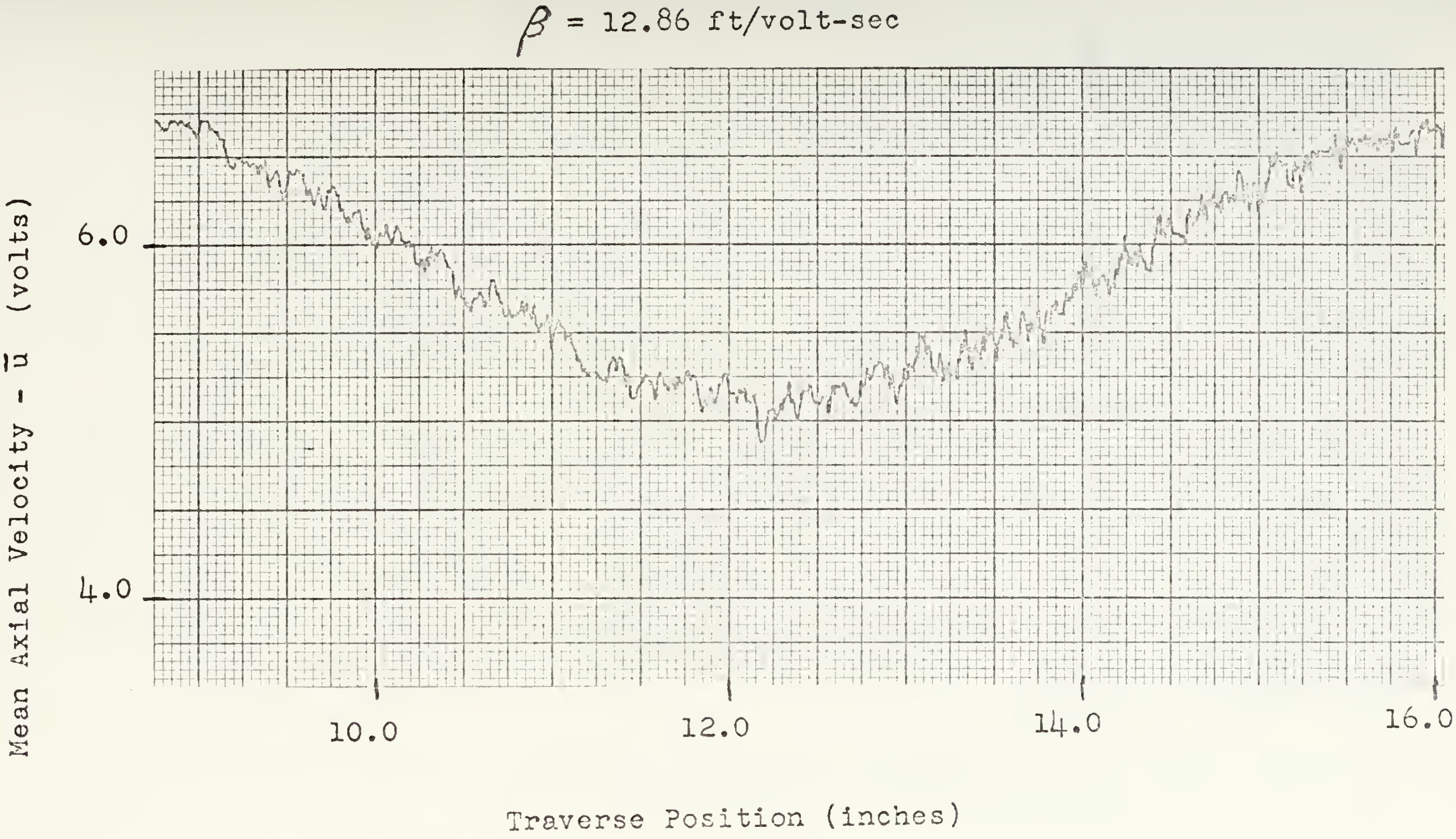


FIGURE 29
Station 9 X-Array Mean Axial Velocity

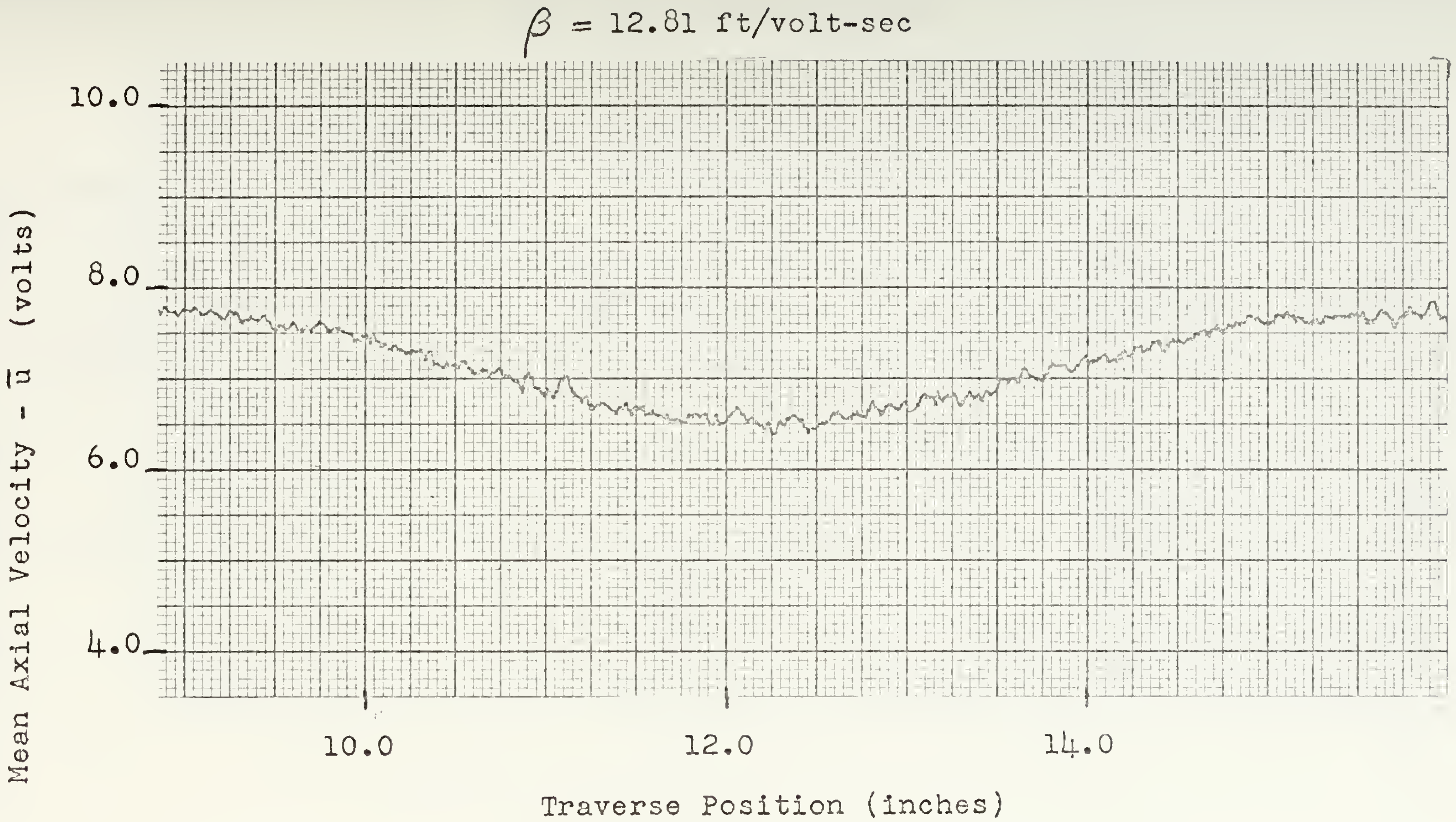


FIGURE 30
Station 10 X-Array Mean Axial Velocity

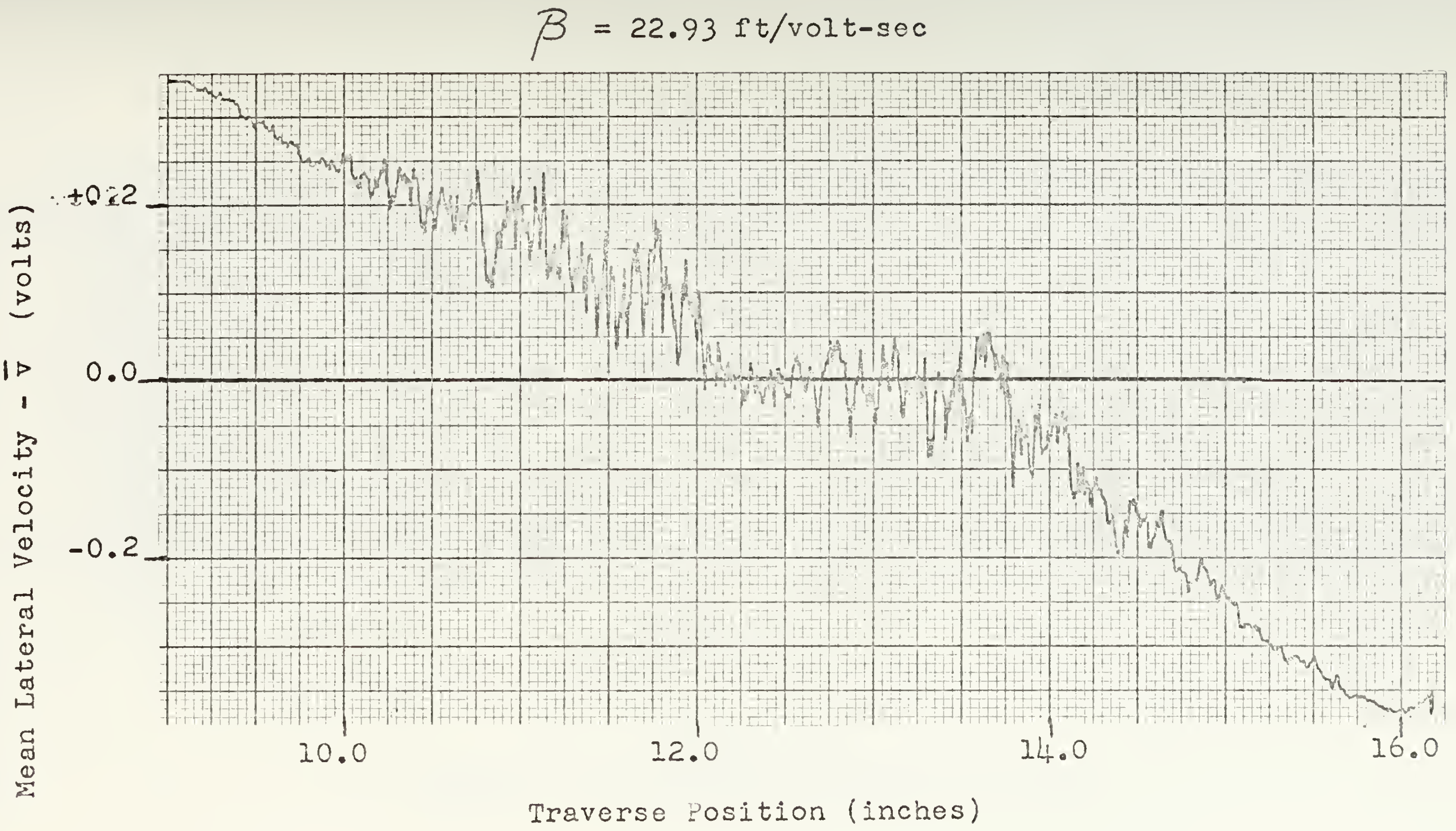


FIGURE 31
Station 1 X-Array Mean Lateral Velocity

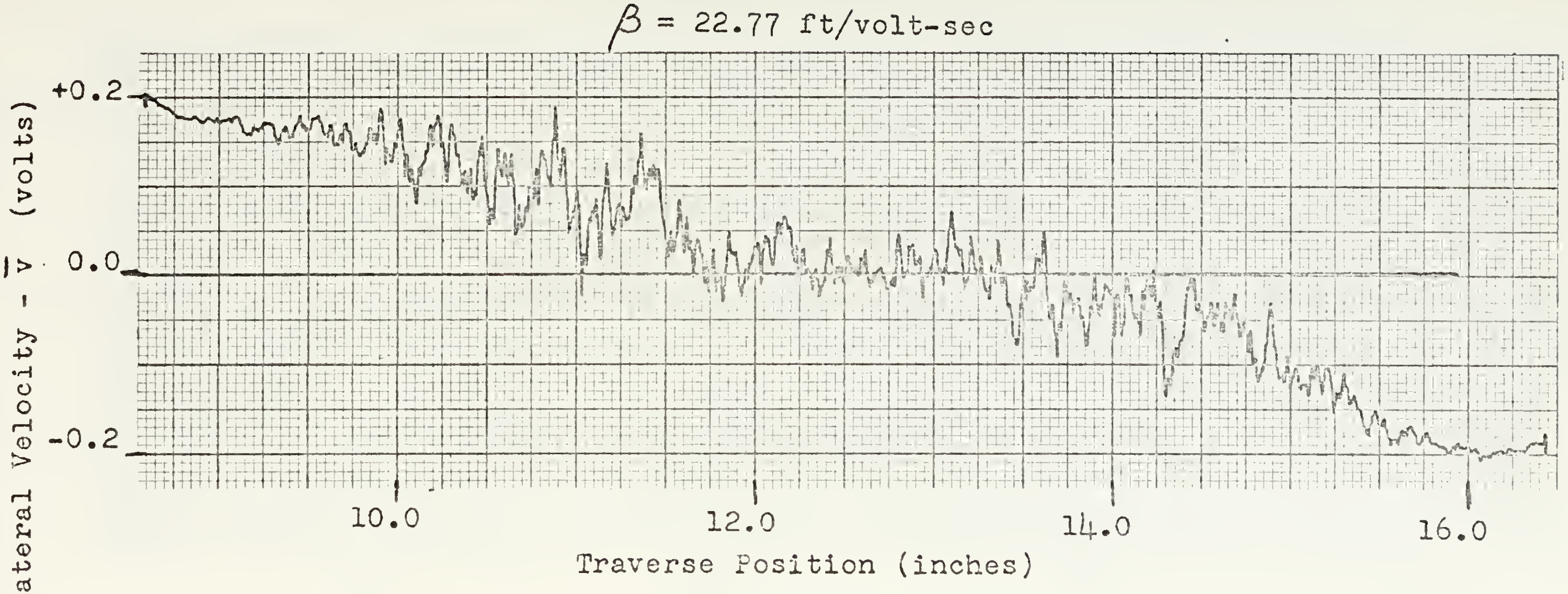


FIGURE 32
Station 2 X-Array Mean Lateral Velocity

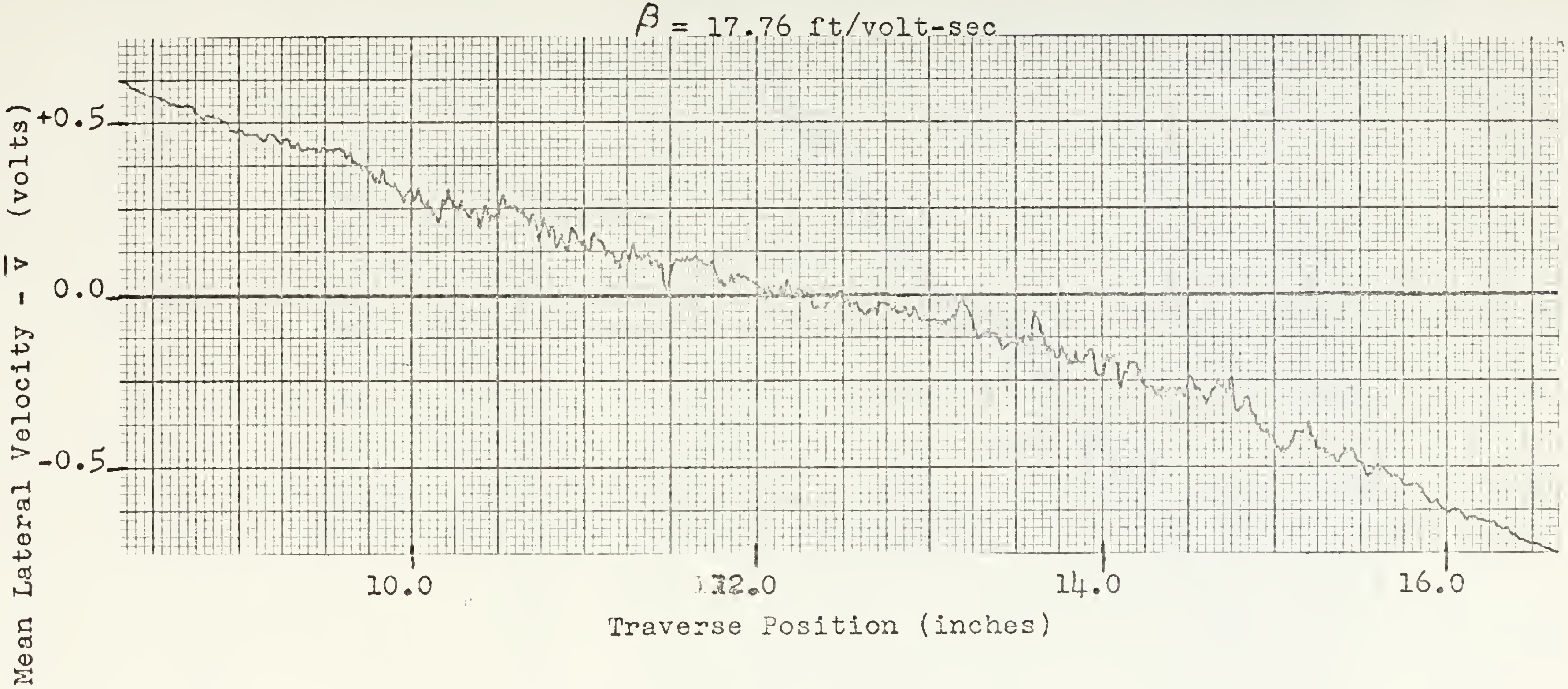


FIGURE 33
Station 3 X-Array Mean Lateral Velocity

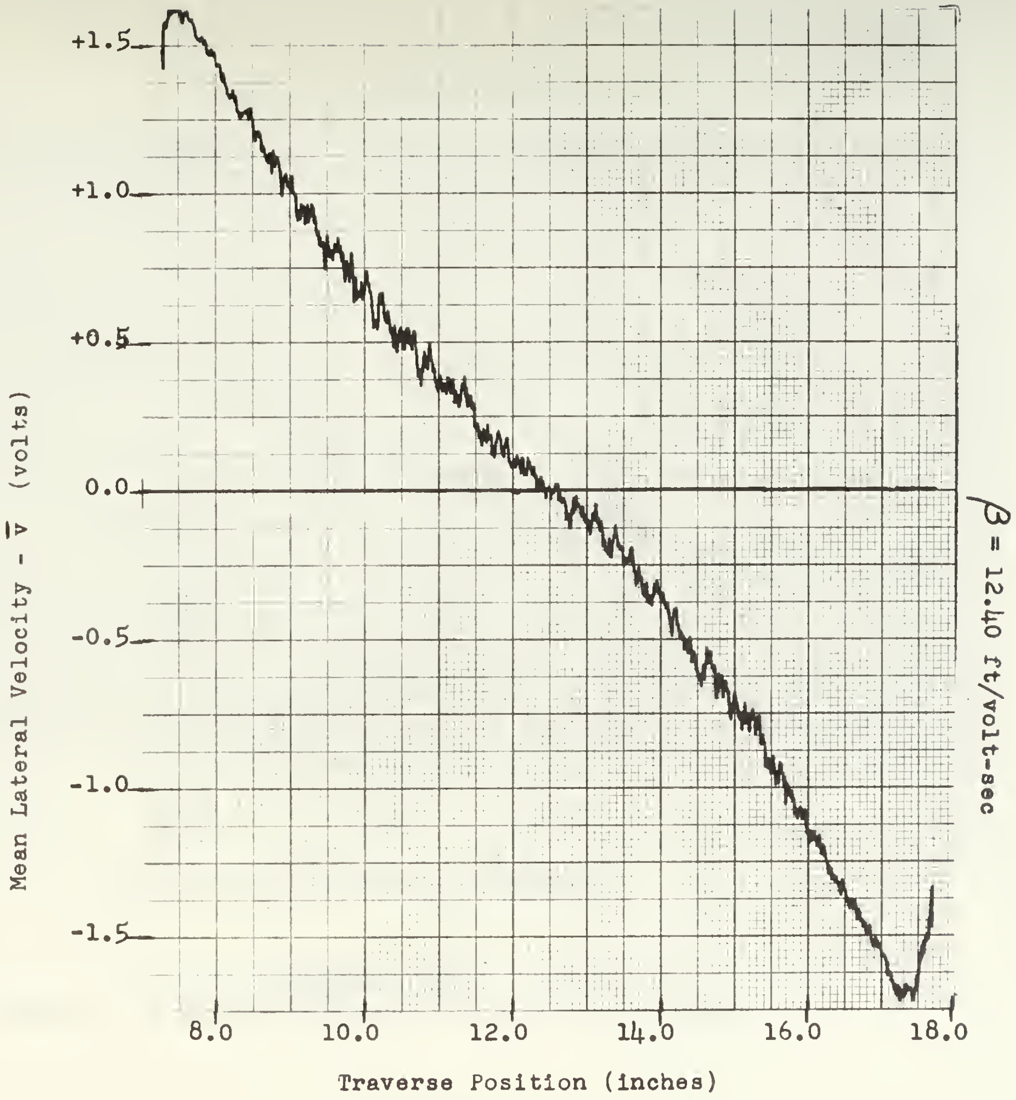


FIGURE 34
Station 4 X-Array Mean Lateral Velocity

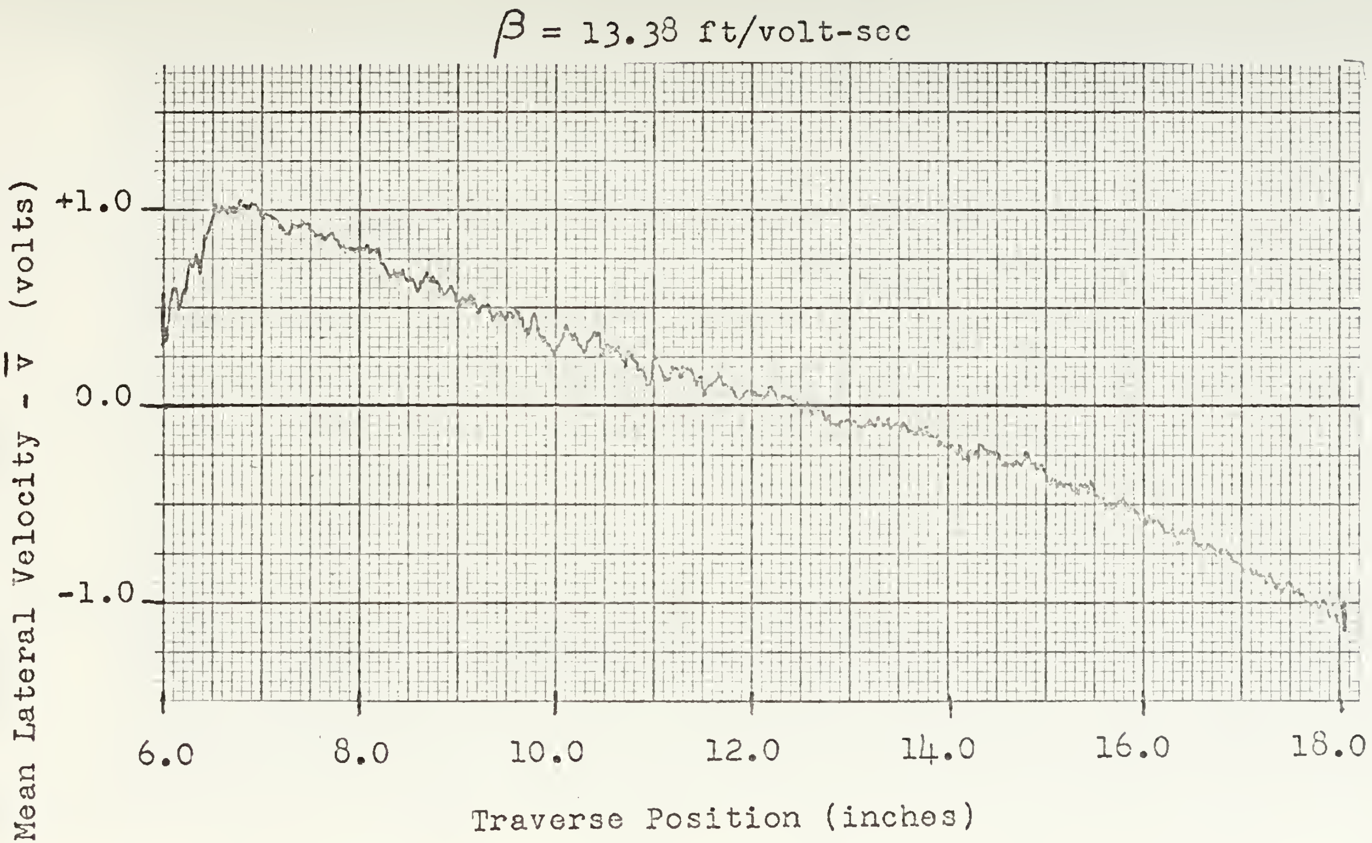


FIGURE 35
Station 5 X-Array Mean Lateral Velocity

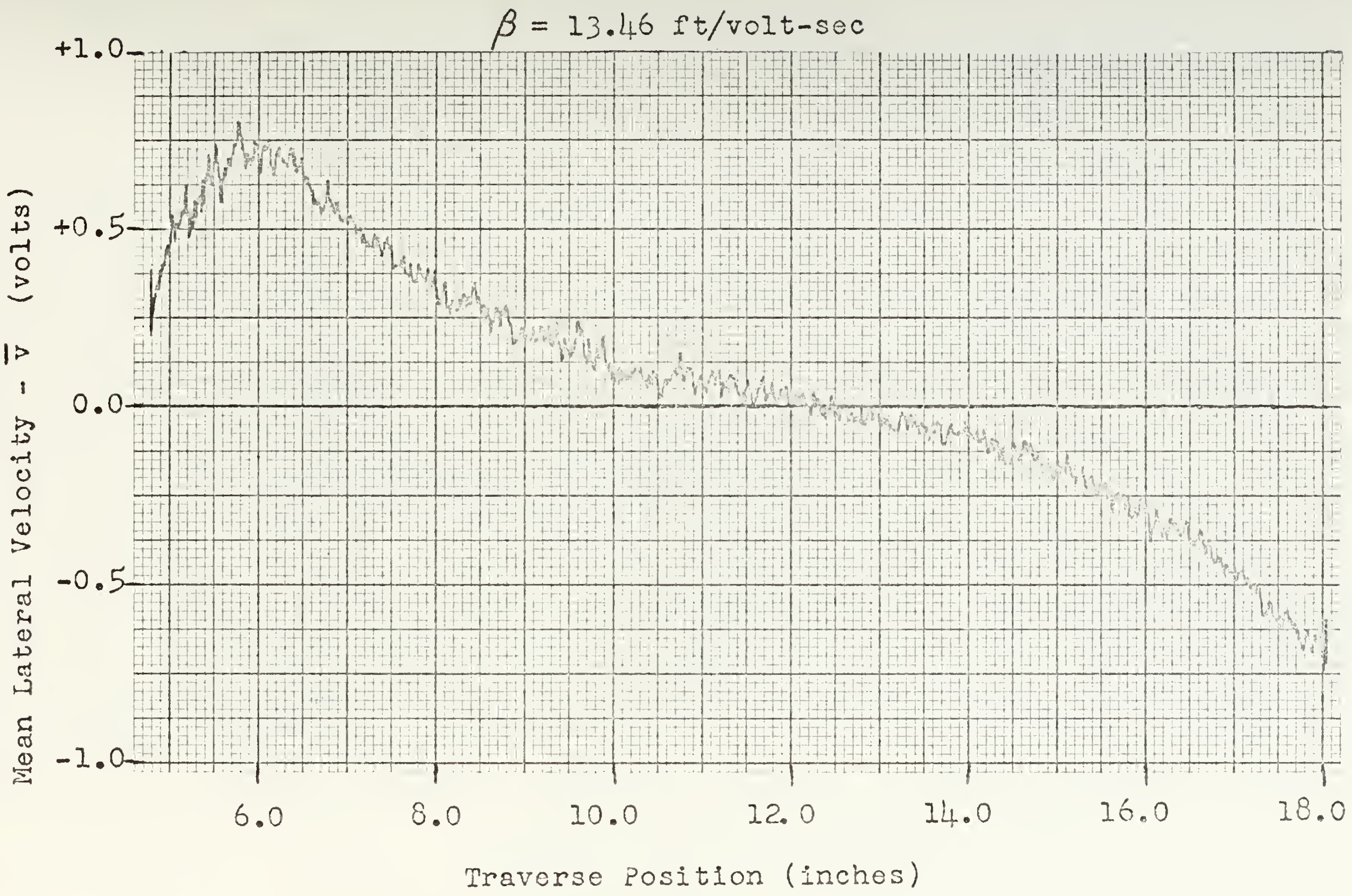


FIGURE 36
Station 6 X-Array Mean Lateral Velocity

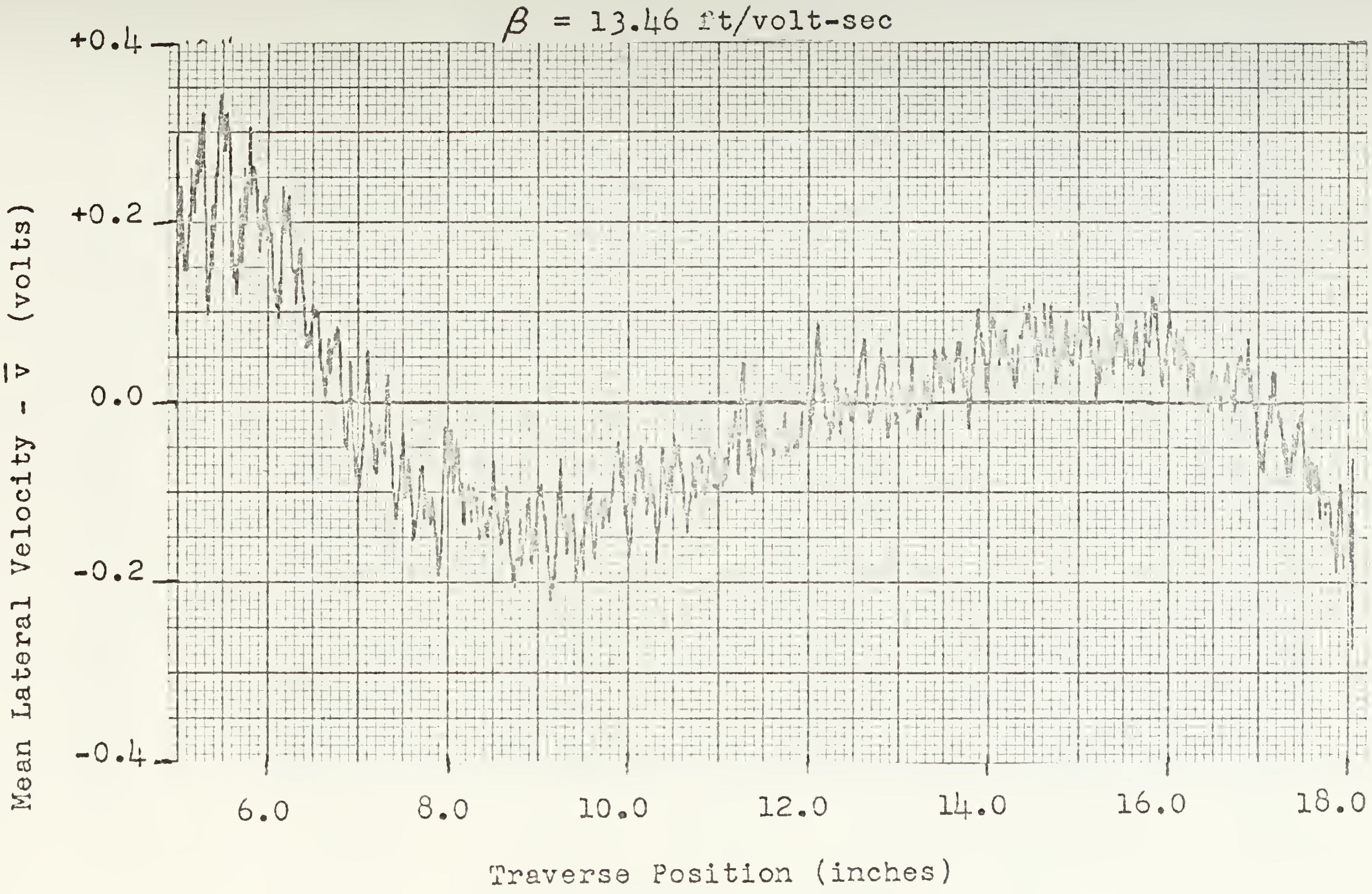


FIGURE 37
Station 7 X-Array Mean Lateral Velocity

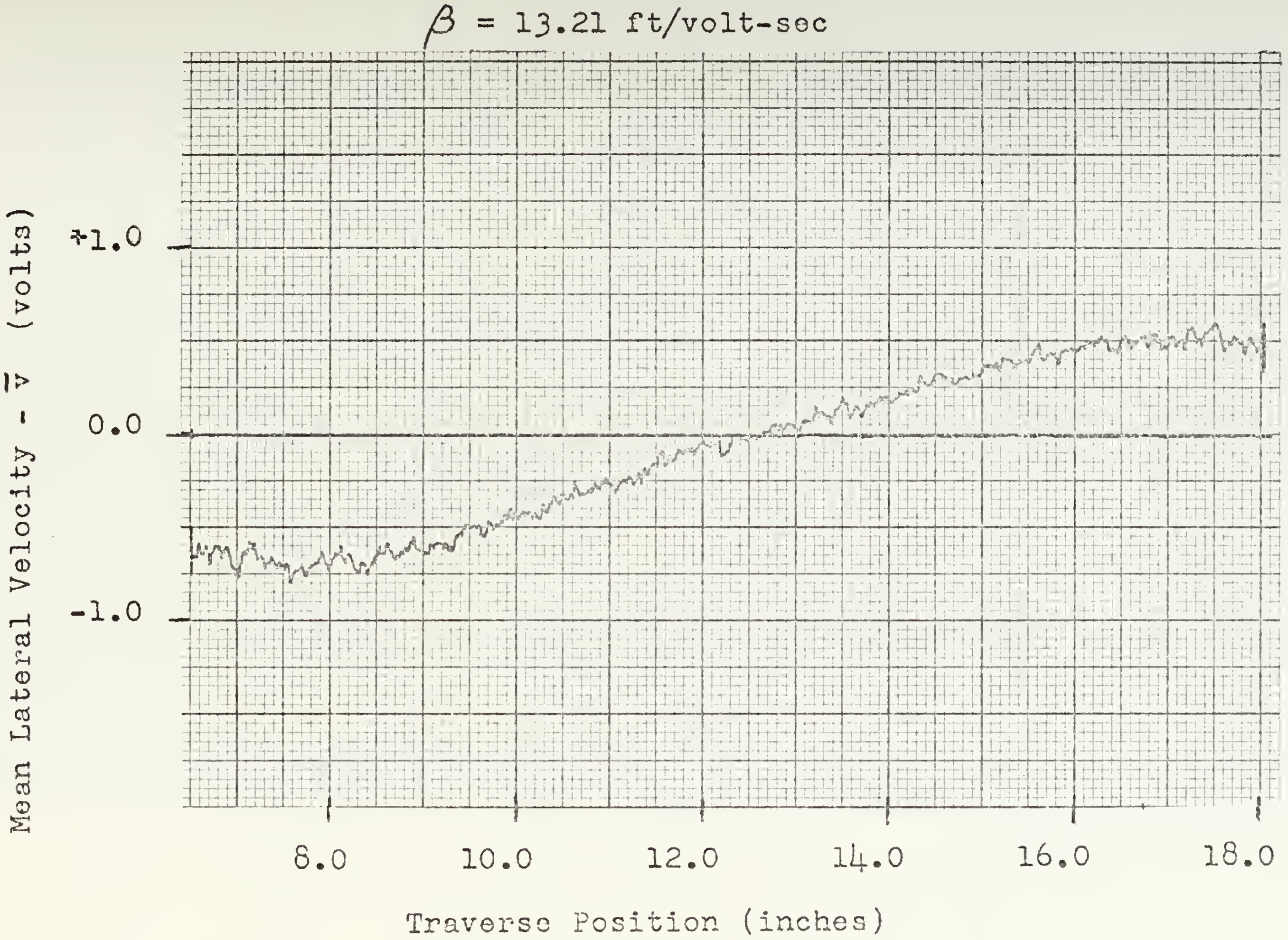


FIGURE 38
Station 8 X-Array Mean Lateral Velocity

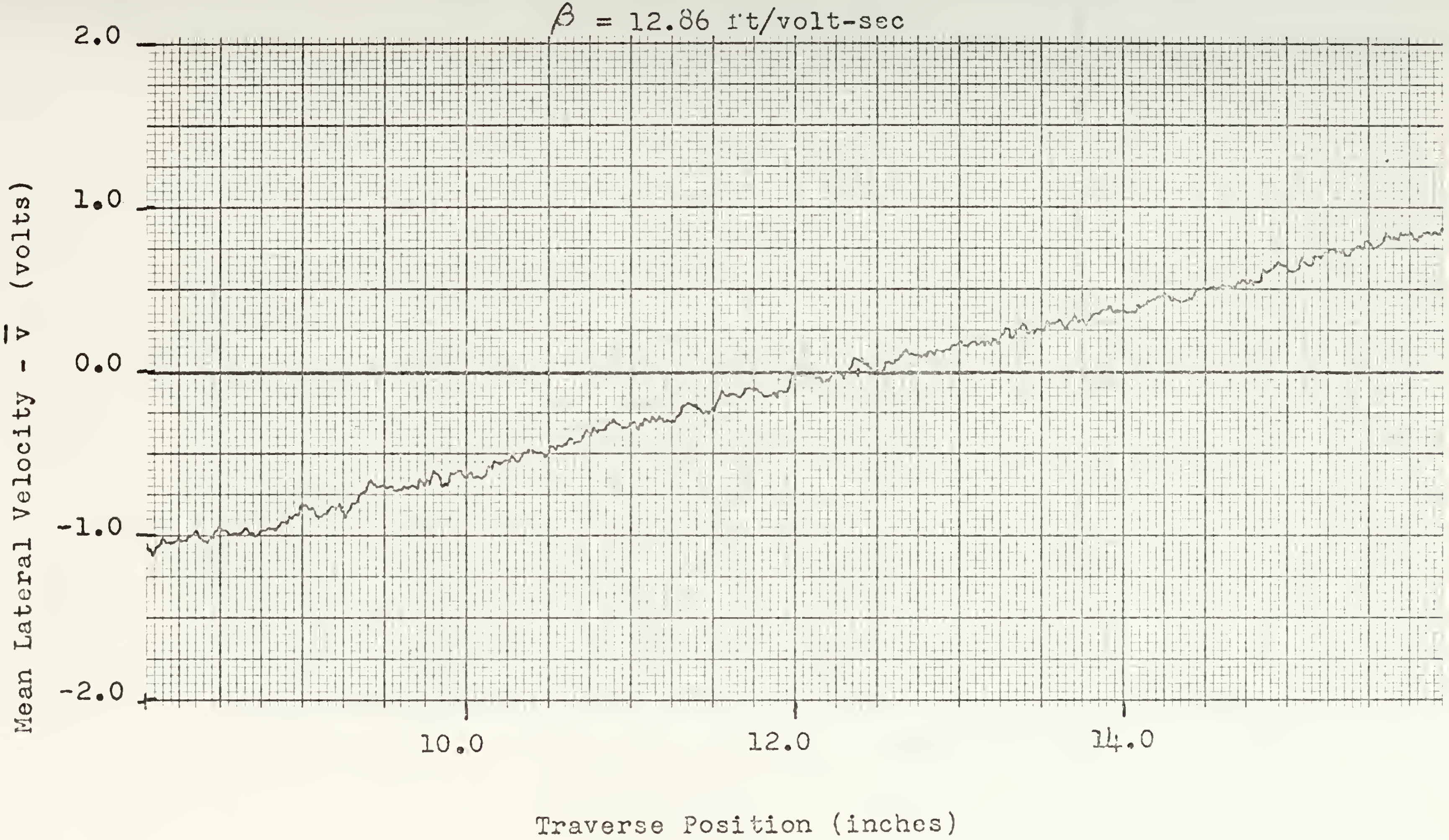


FIGURE 39
Station 9 X-Array Mean Lateral Velocity

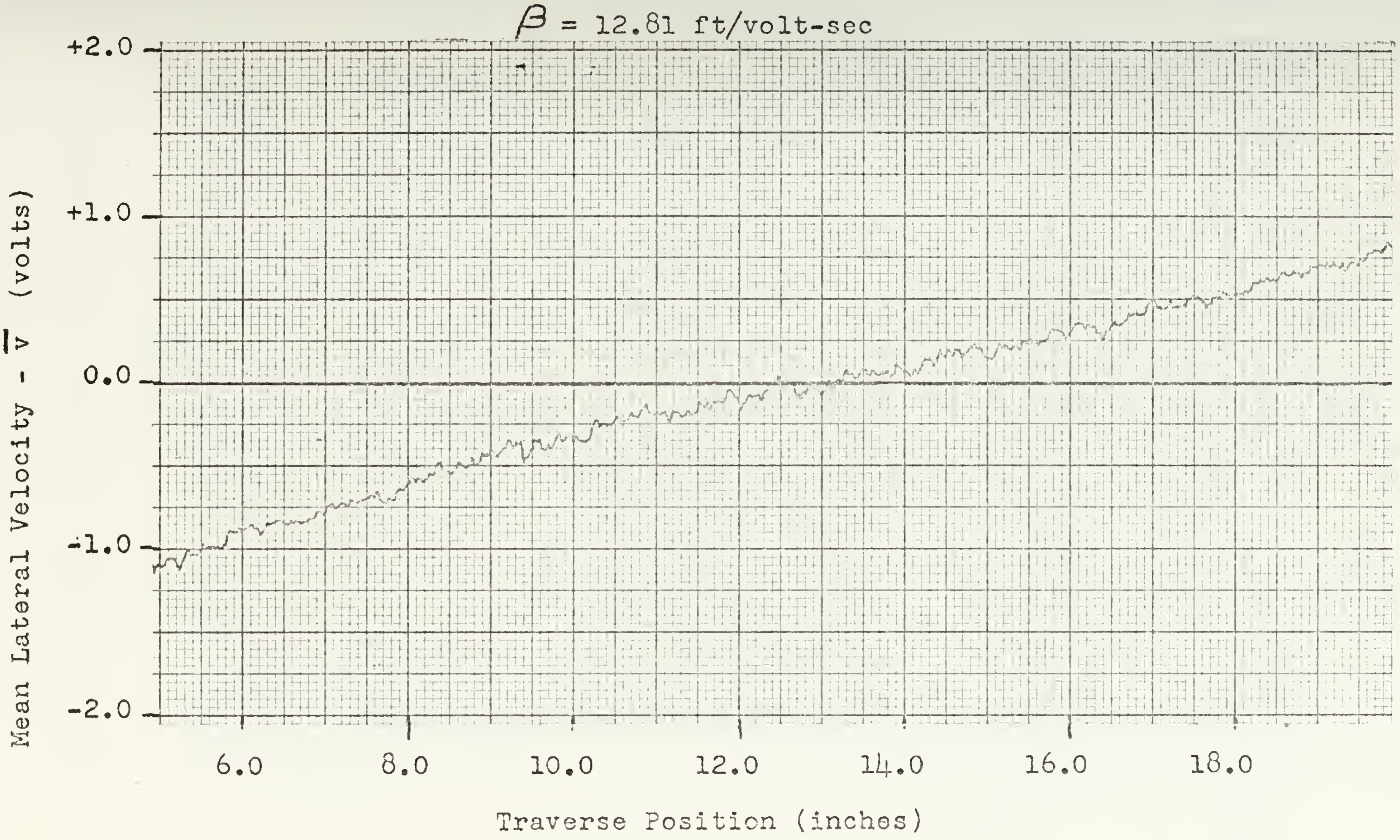


FIGURE 40
Station 10 X-Array Mean Lateral Velocity

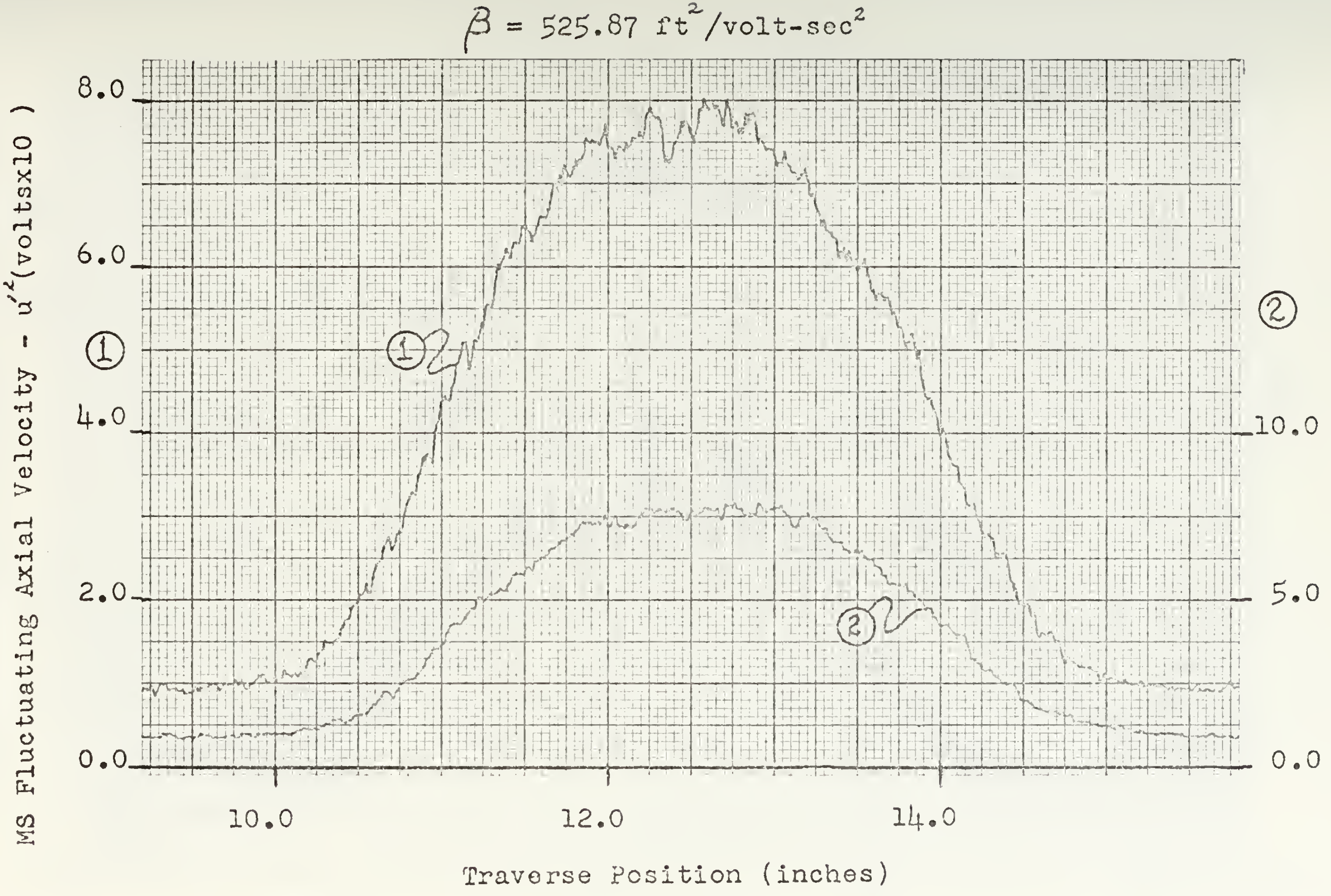


FIGURE 41
Station 1 X-Array MS Fluctuating Axial Velocity

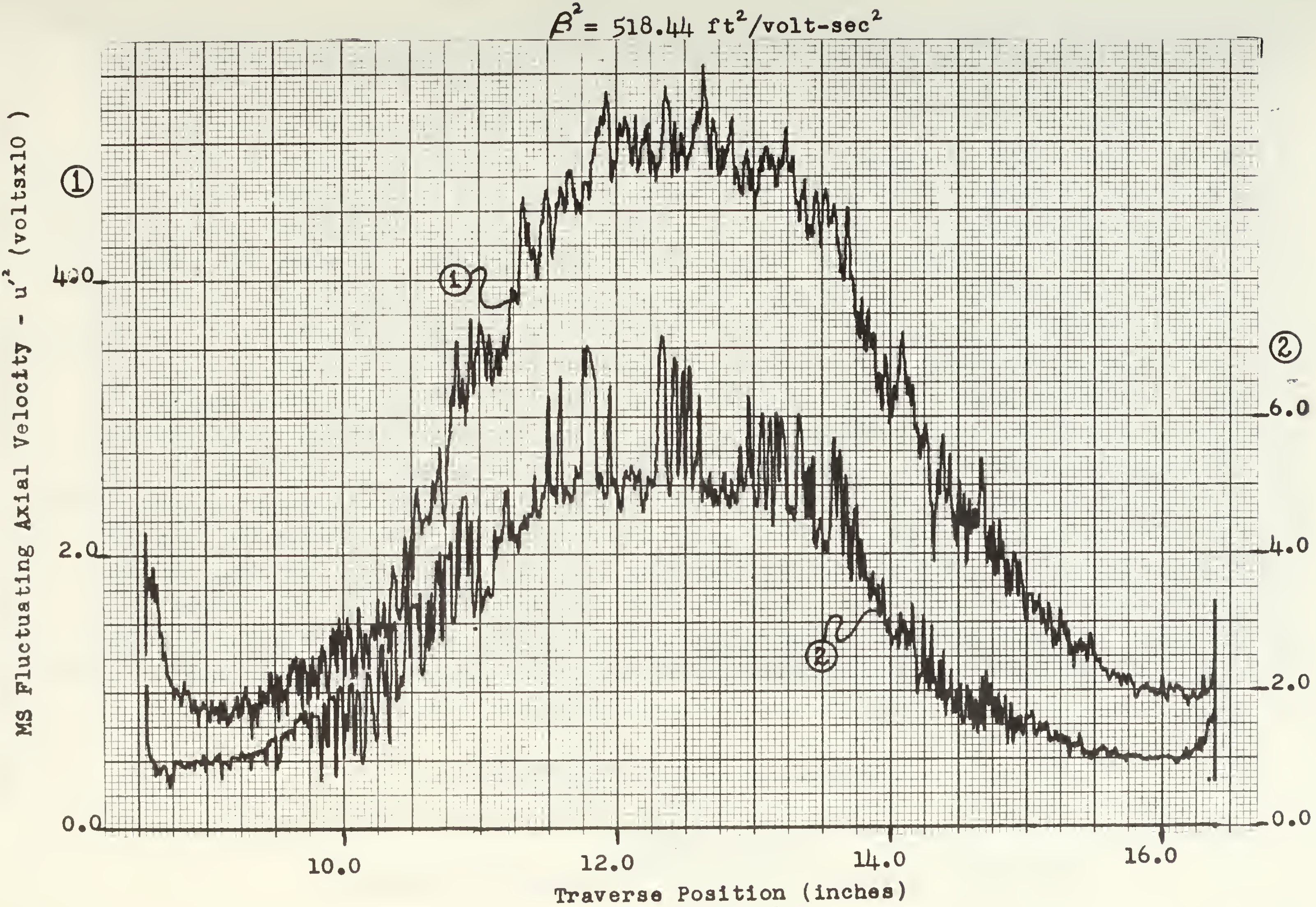


FIGURE 42
Station 2 X-Array MS Fluctuating Axial Velocity

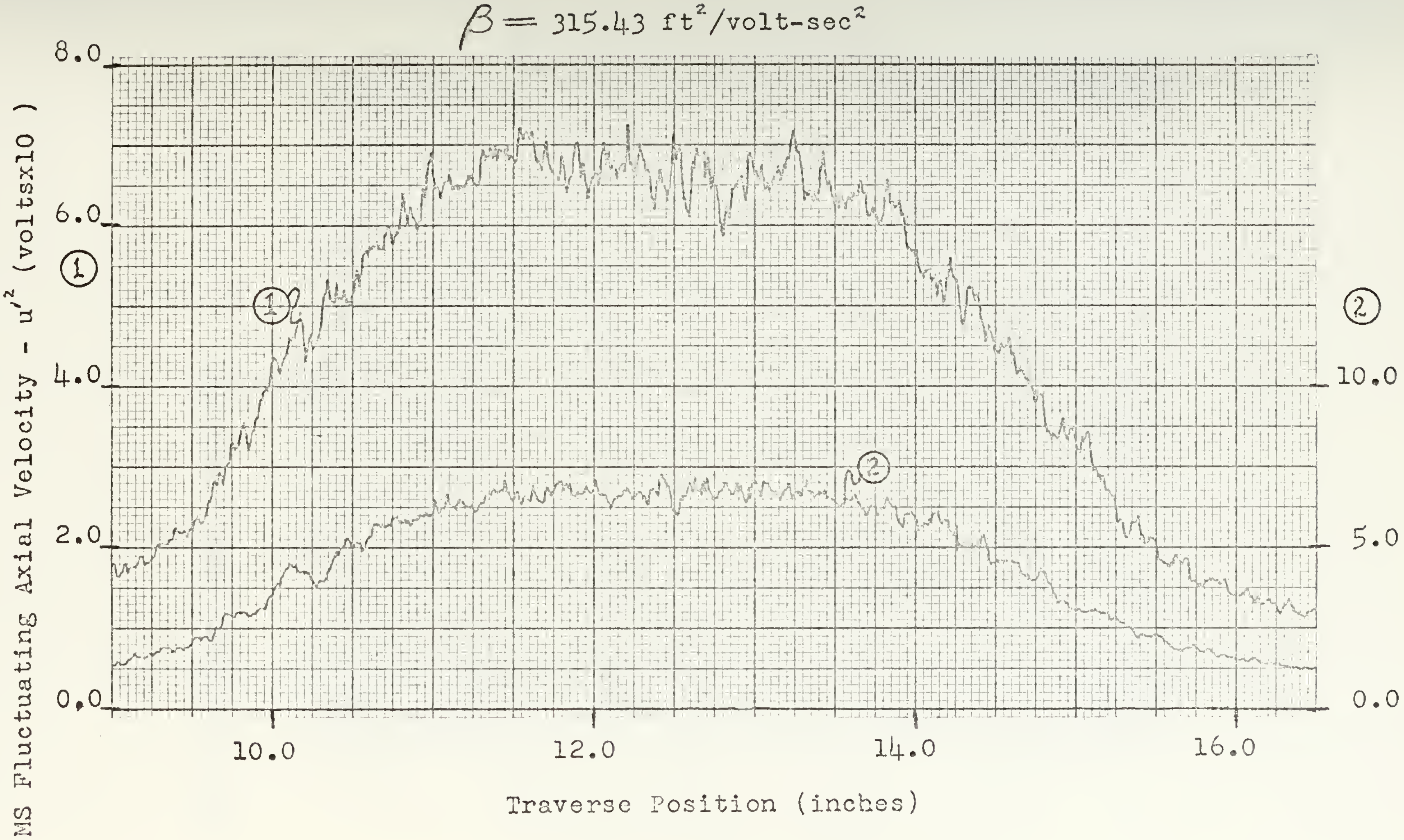


FIGURE 43
Station 3 X-Array MS Fluctuating Axial Velocity

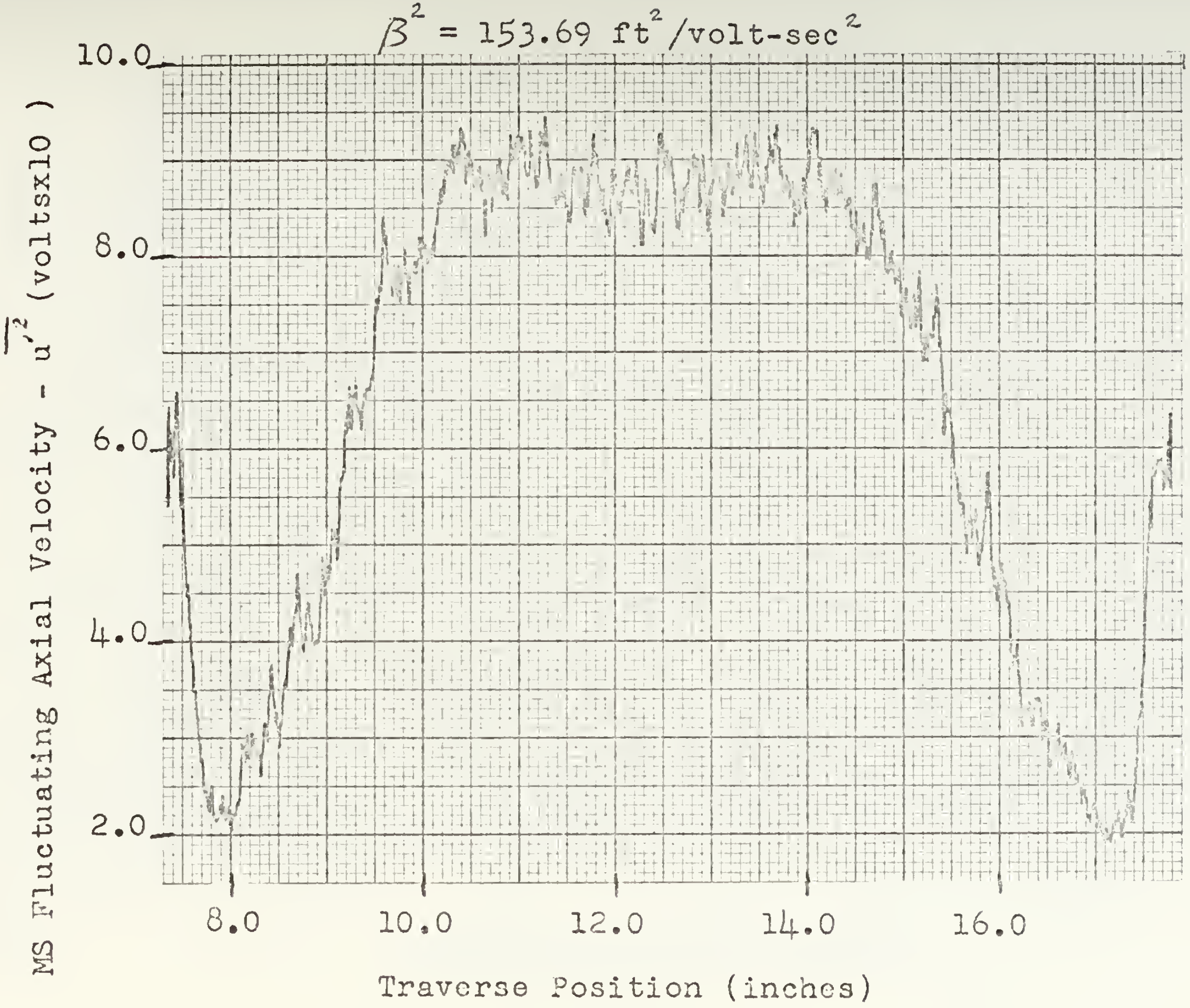


FIGURE 44
Station 4 X-Array MS Fluctuating Axial Velocity

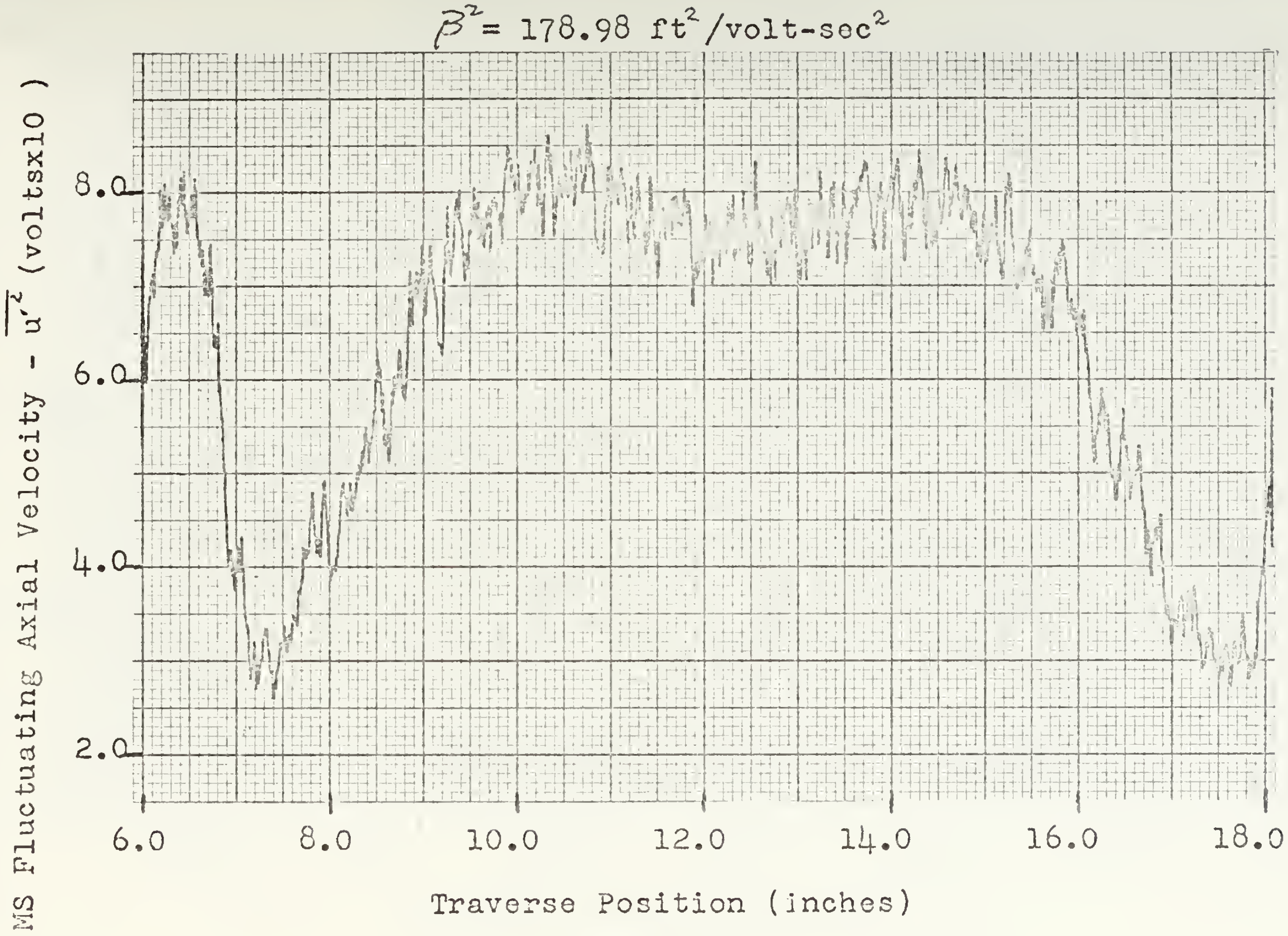


FIGURE 45
Station 5 X-Array MS Fluctuating Axial Velocity

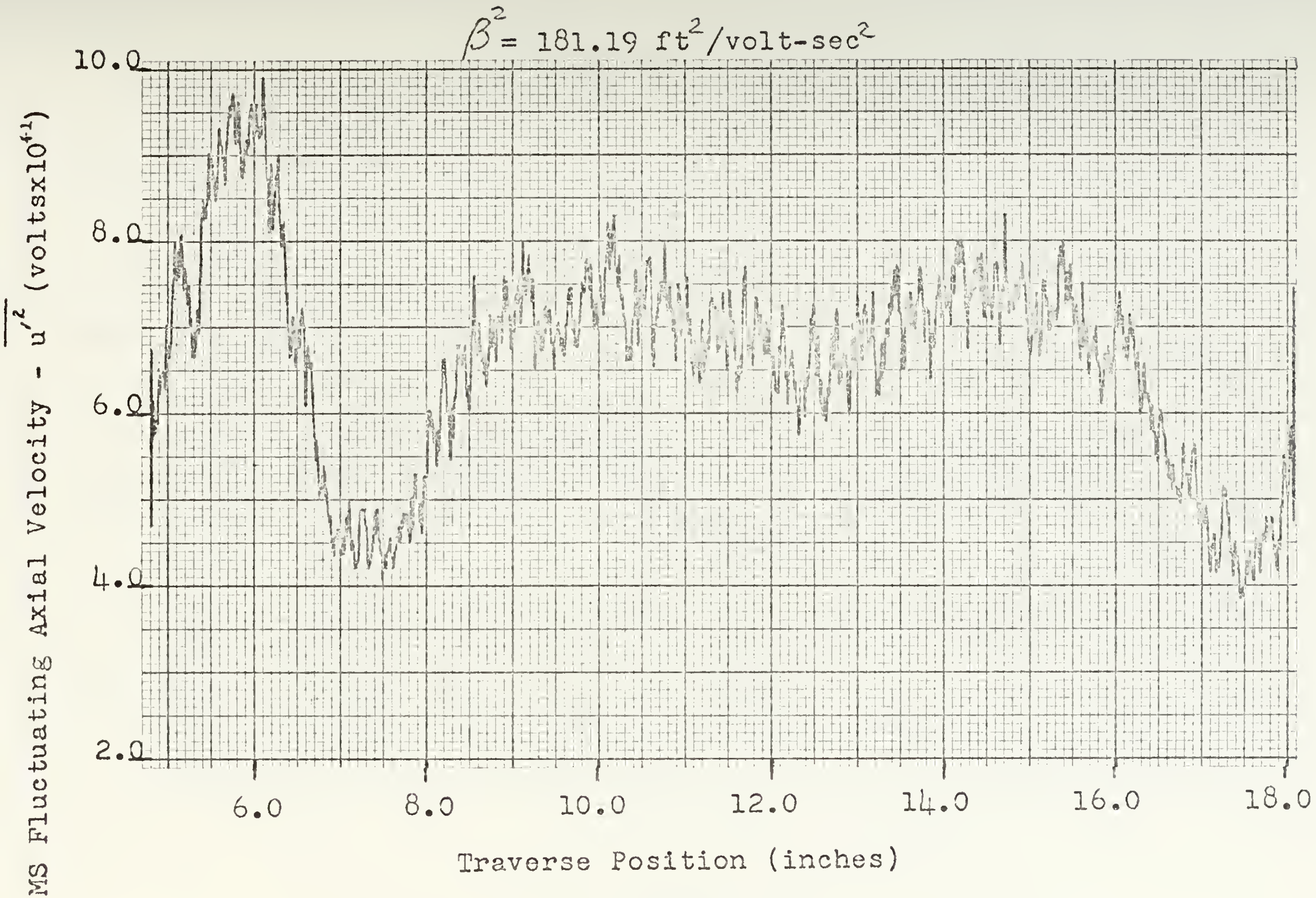


FIGURE 46
Station 6 X-Array MS Fluctuating Axial Velocity

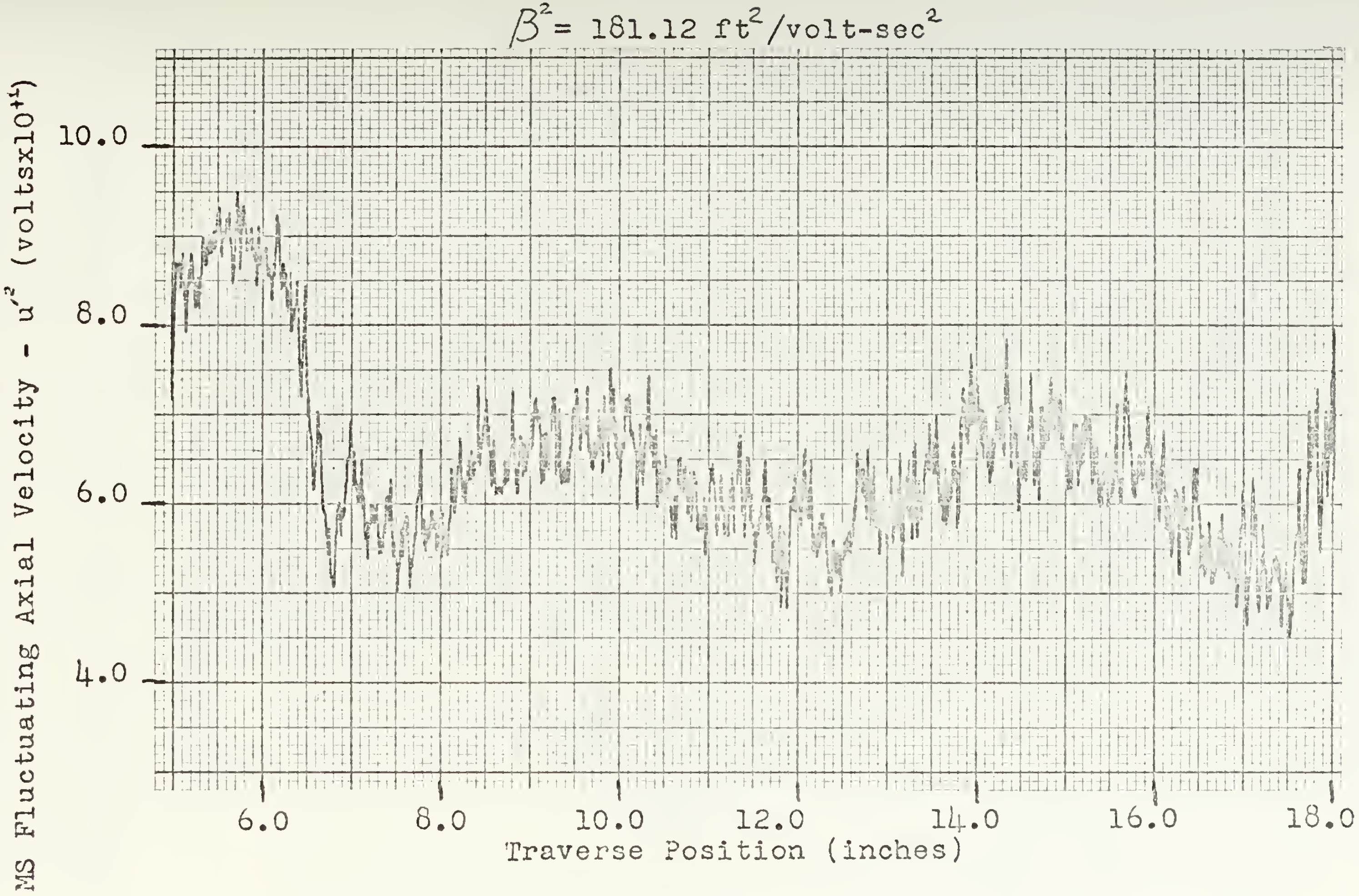


FIGURE 47
Station 7 X-Array MS Fluctuating Axial Velocity

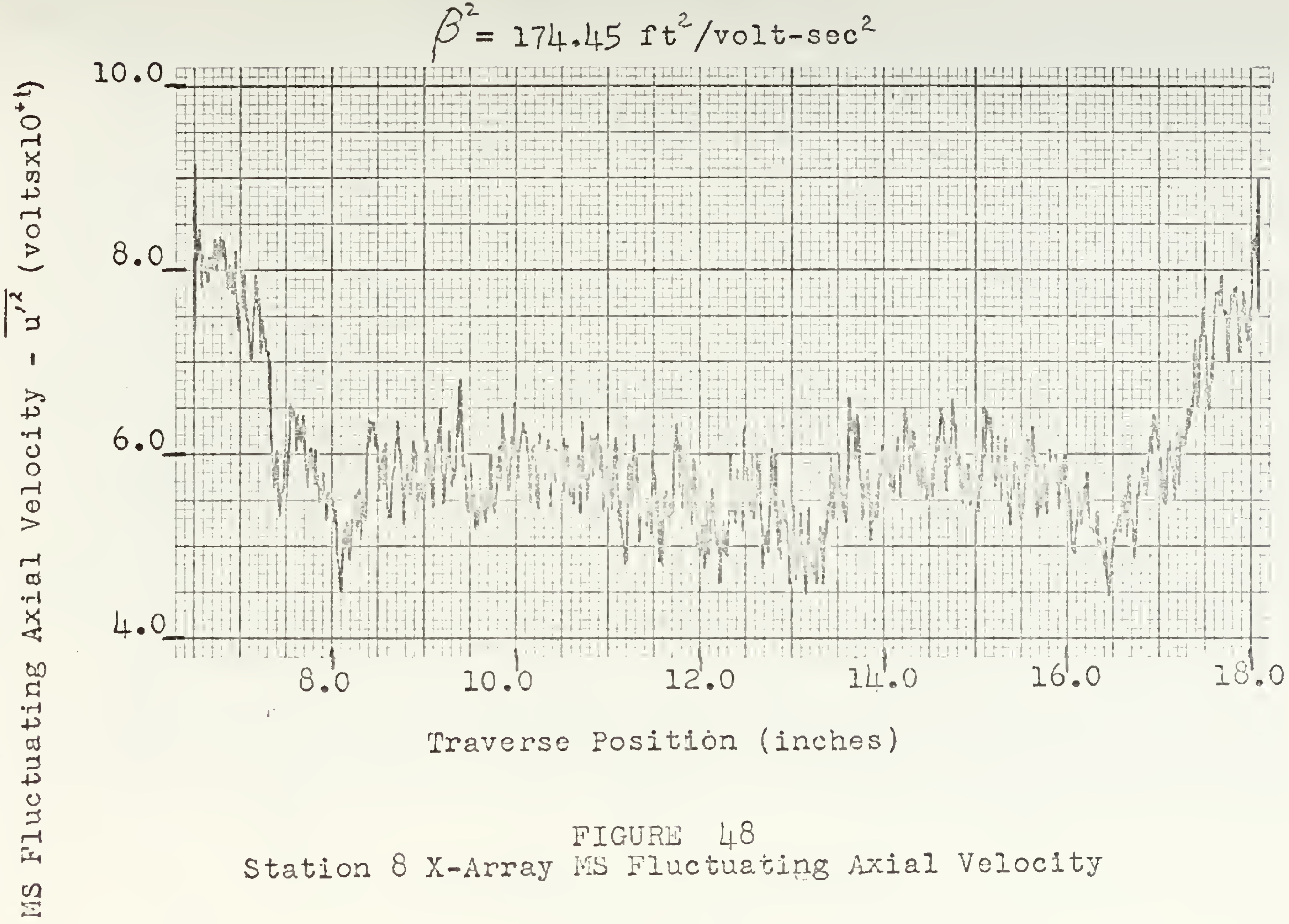


FIGURE 48
Station 8 X-Array MS Fluctuating Axial Velocity

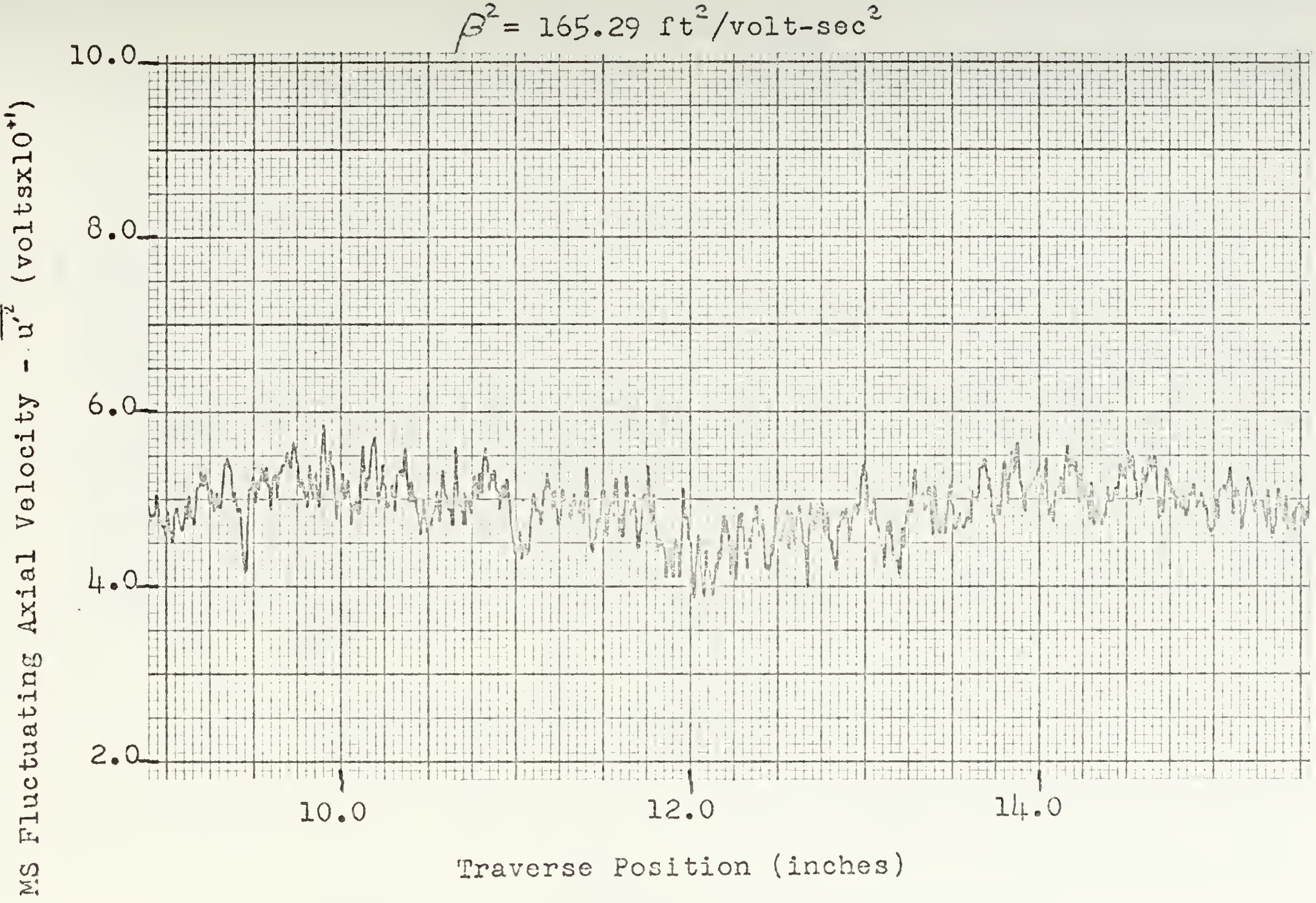


FIGURE 49
Station 9 X-Array MS Fluctuating Axial Velocity

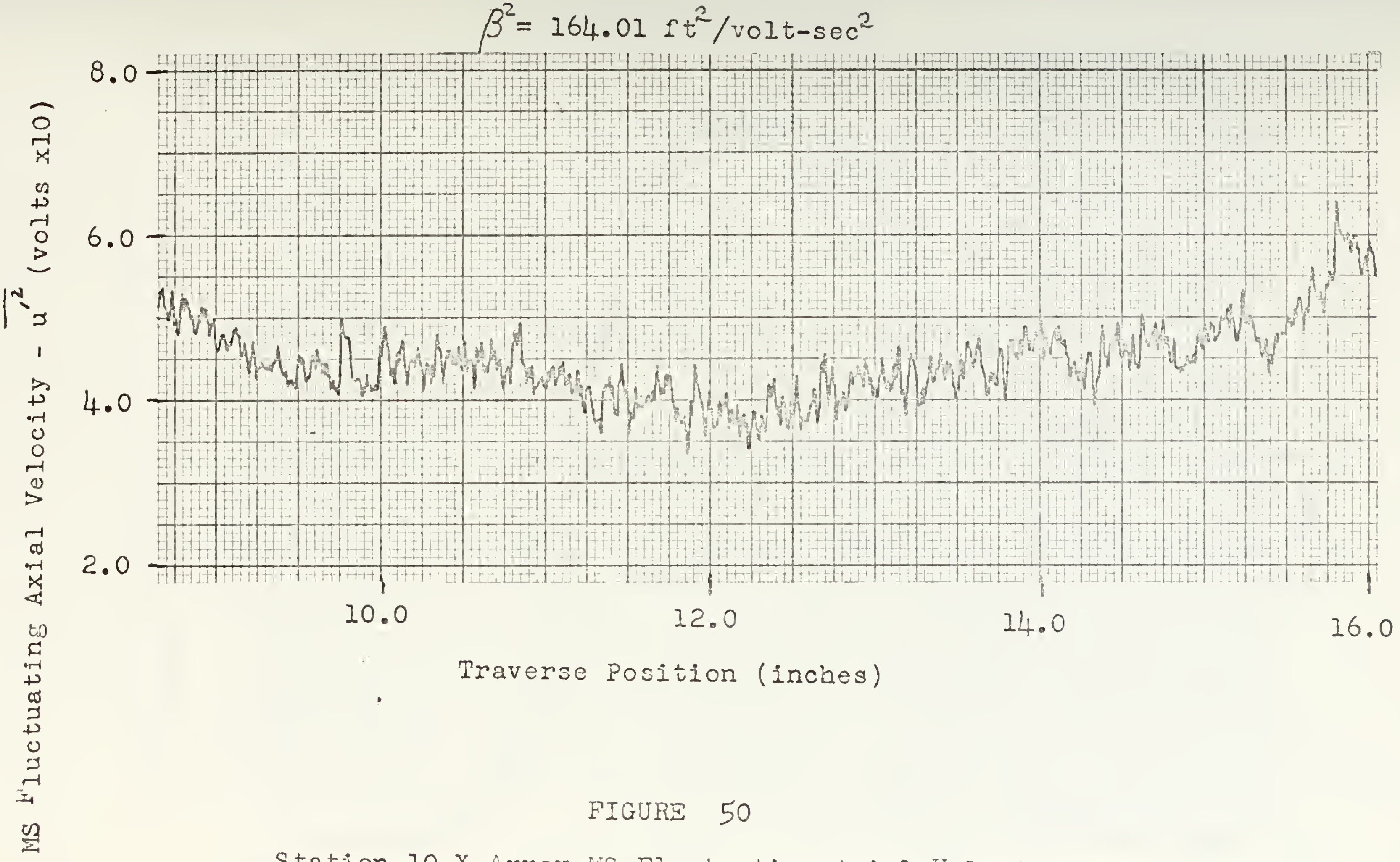


FIGURE 50

Station 10 X-Array MS Fluctuating Axial Velocity

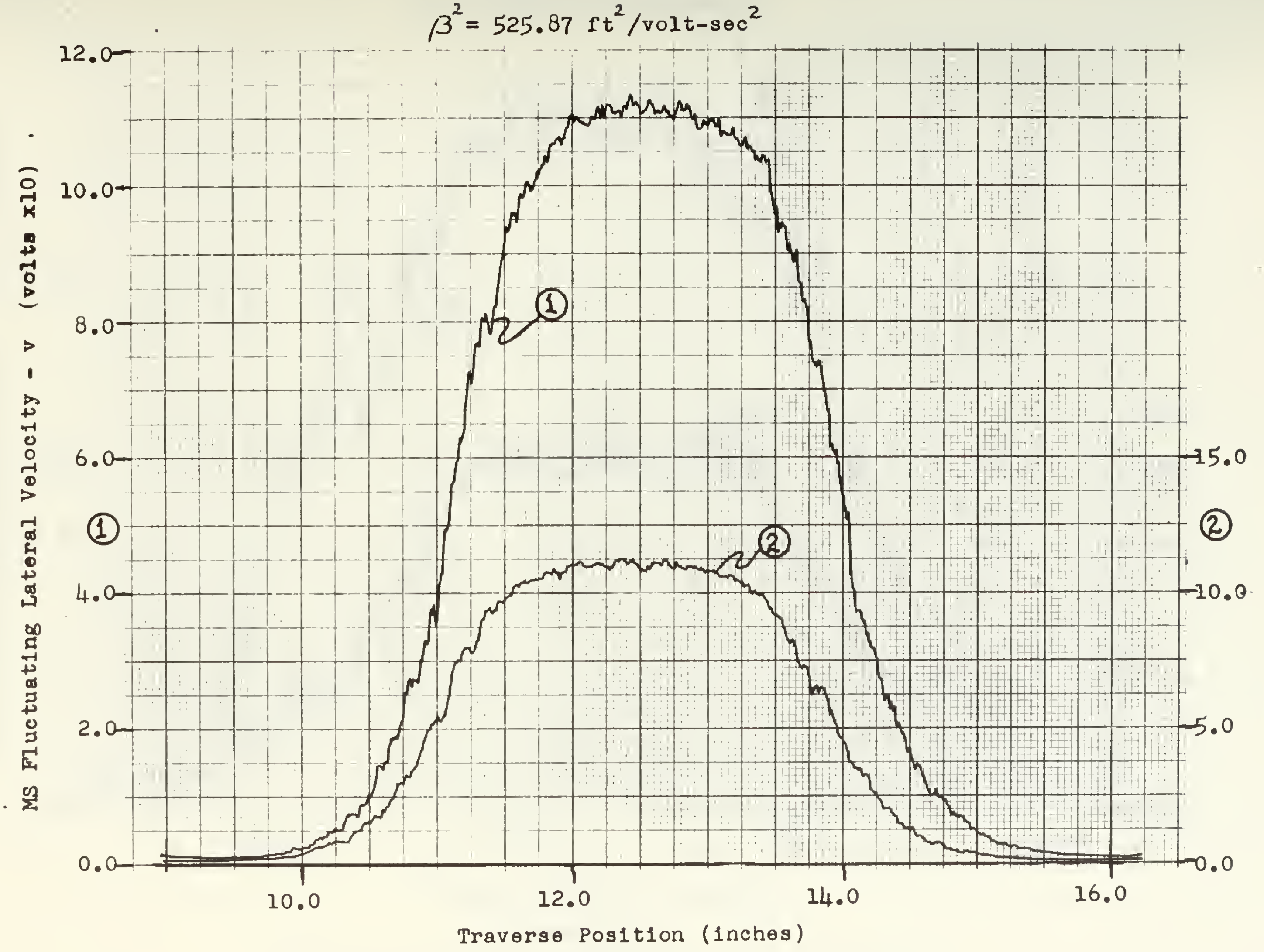
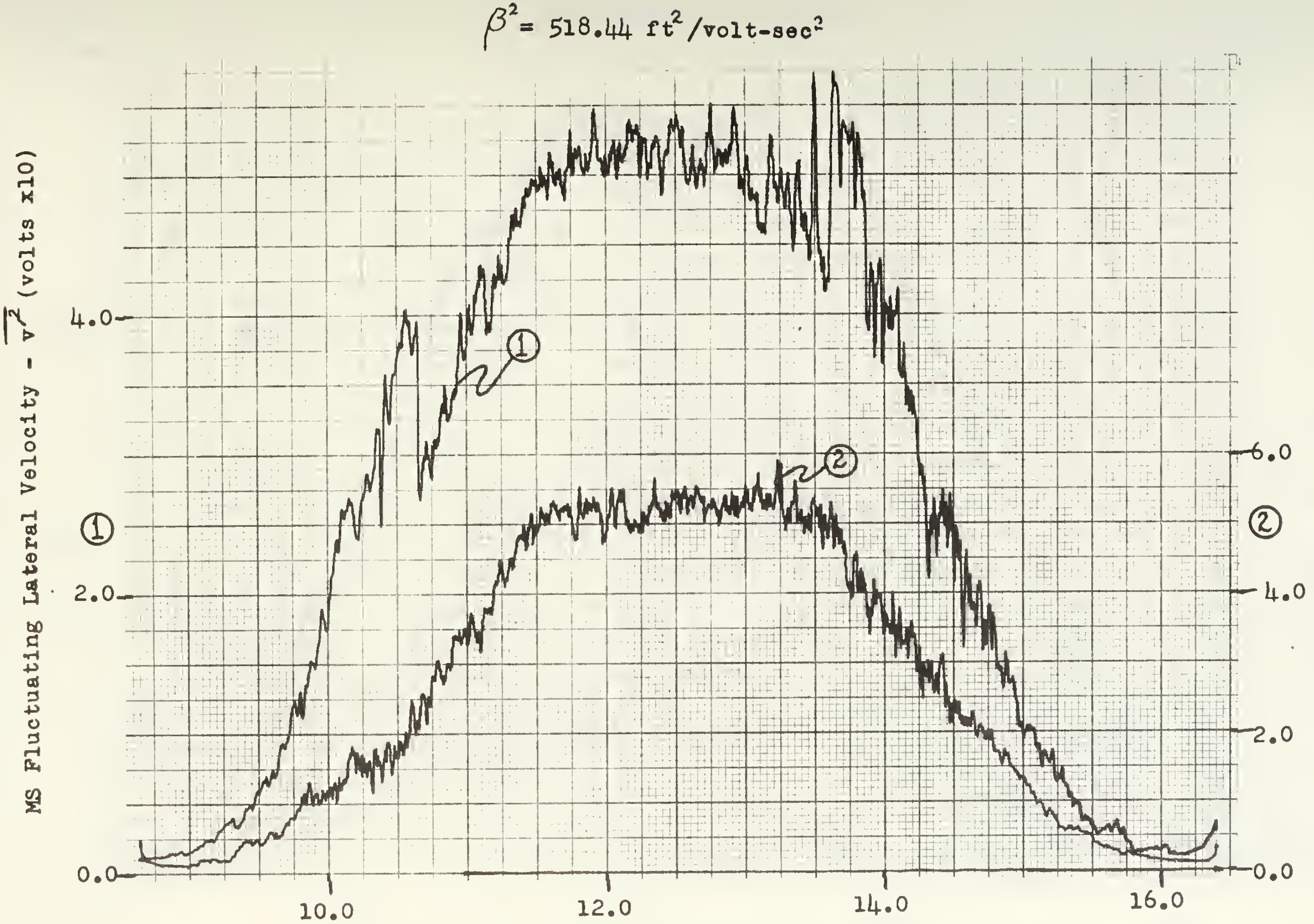


FIGURE 51
Station 1 X-Array MS Fluctuating Lateral Velocity

[illegible]



Traverse Position (inches)

FIGURE 52

Station 2 X-Array MS Fluctuating Lateral Velocity

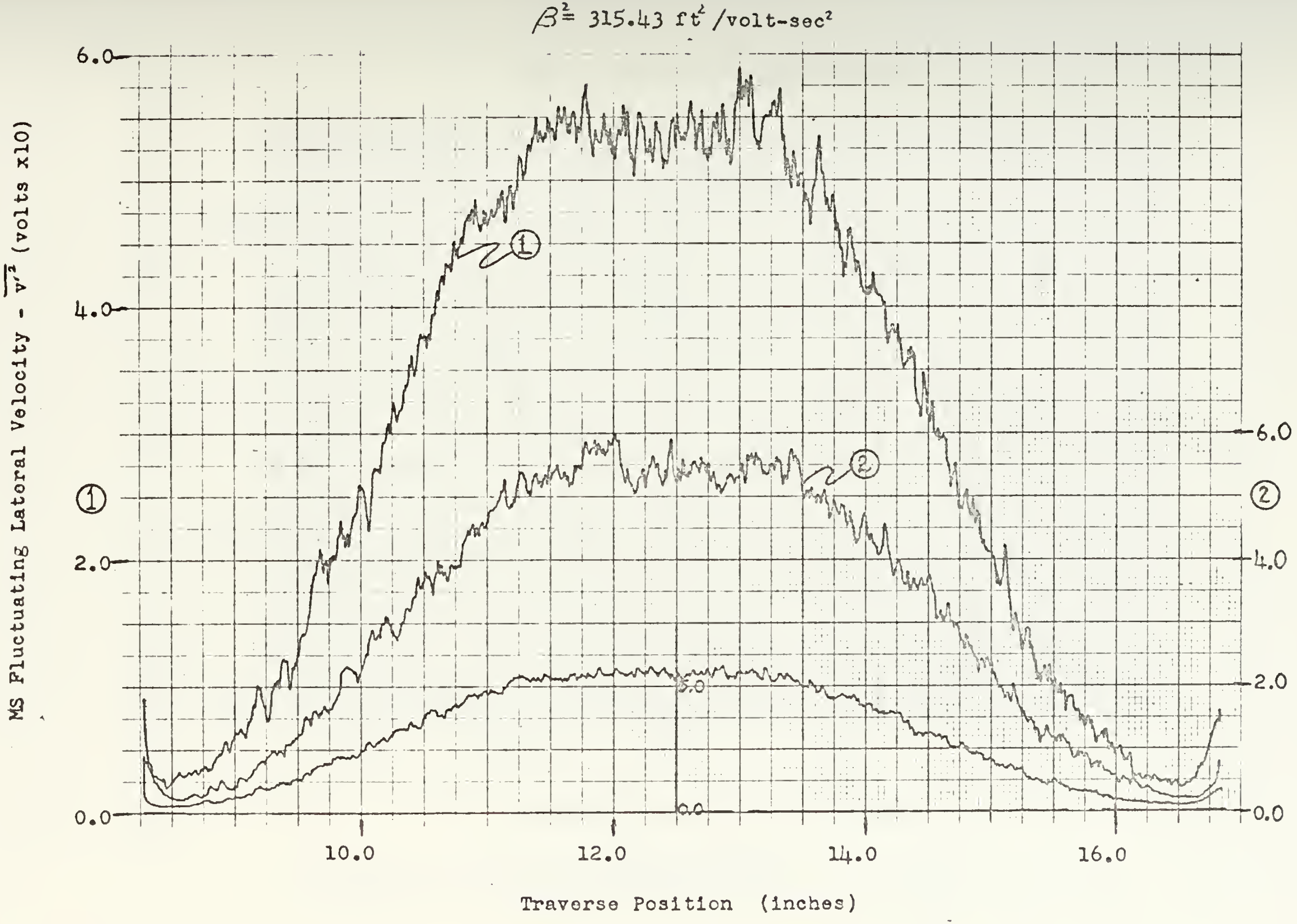


FIGURE 53
Station 3 X-Array MS Fluctuating Lateral Velocity

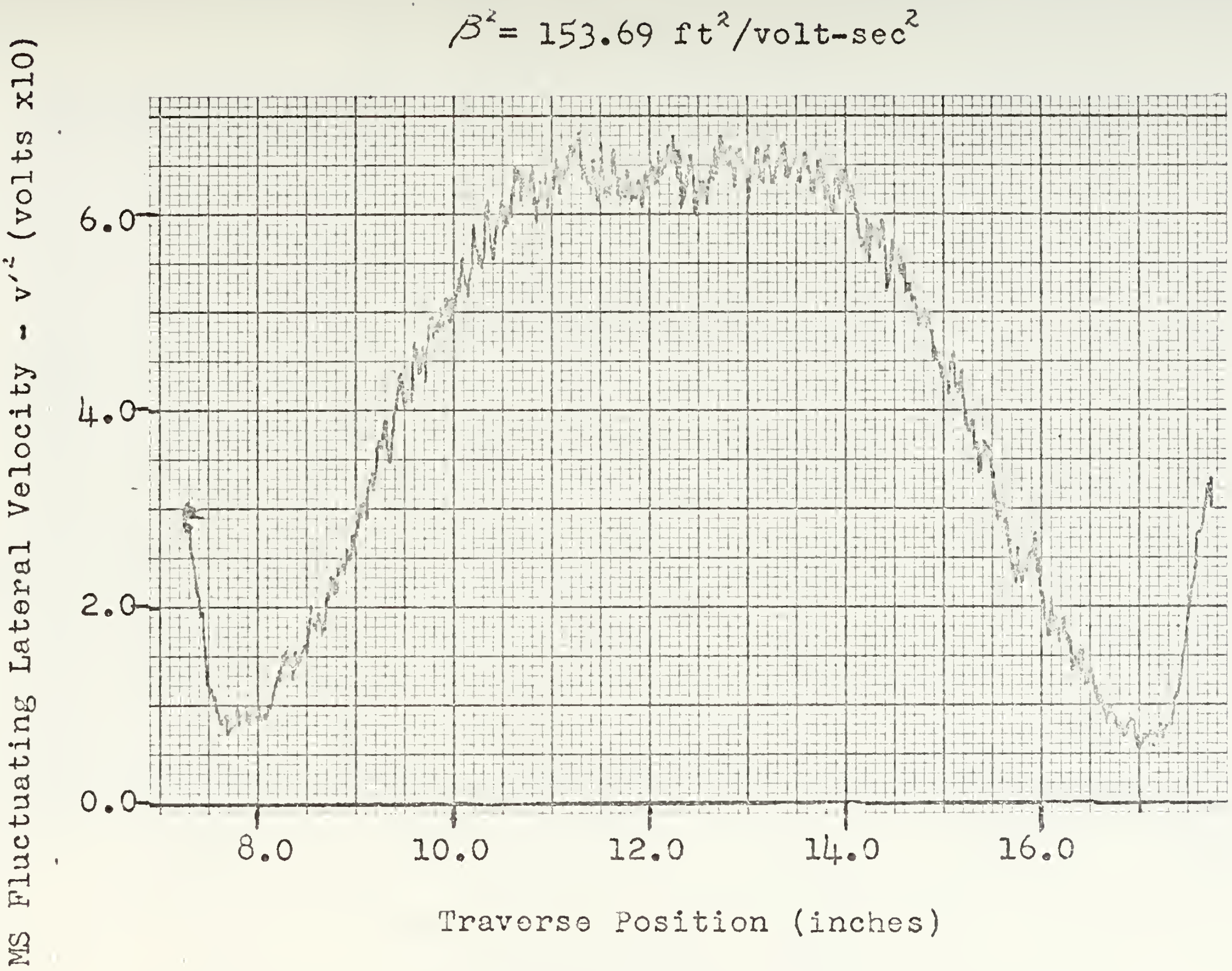


FIGURE 54
Station 4 X-Array MS Fluctuating Lateral Velocity

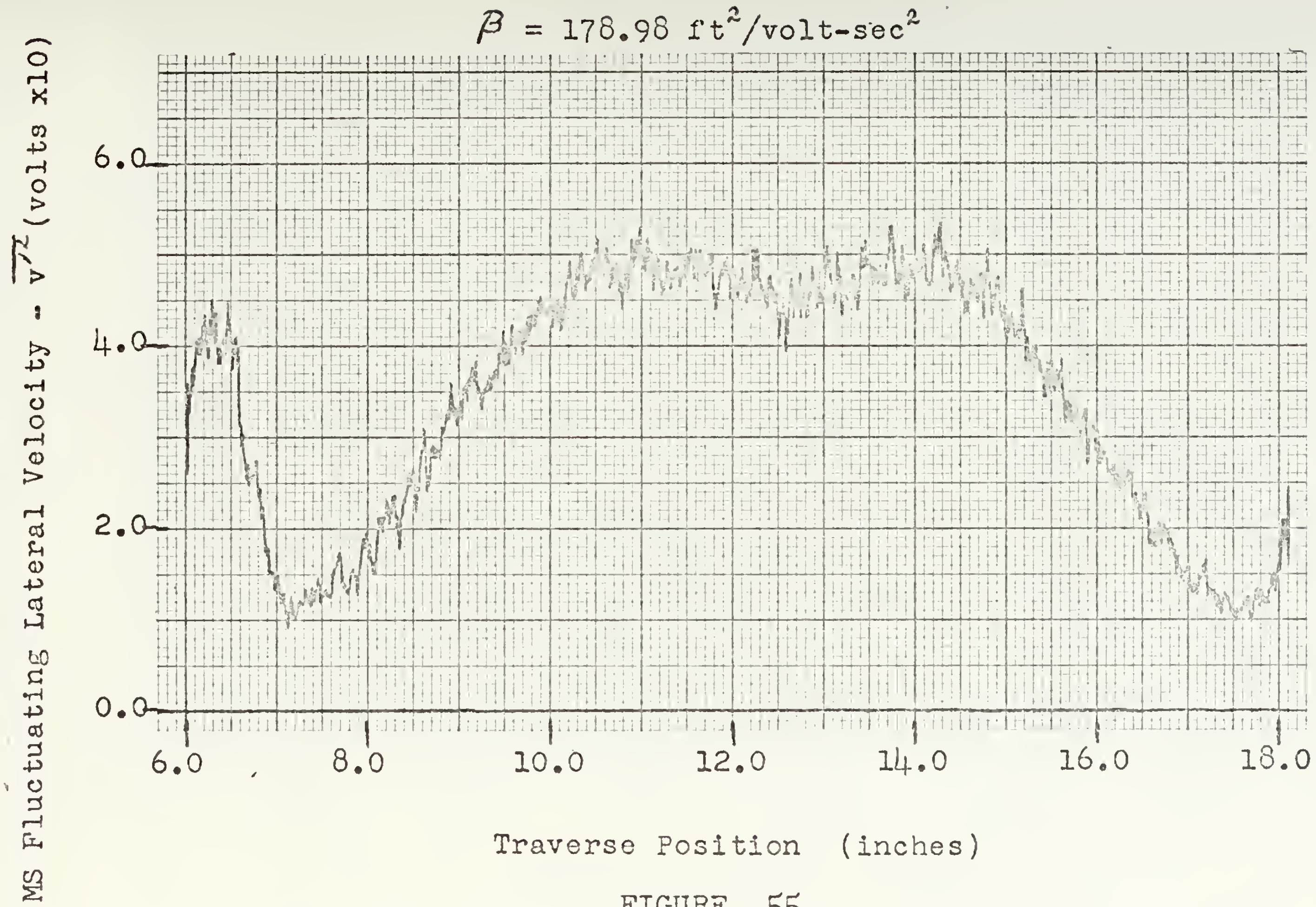


FIGURE 55
Station 5 X-Array MS Fluctuating Lateral Velocity

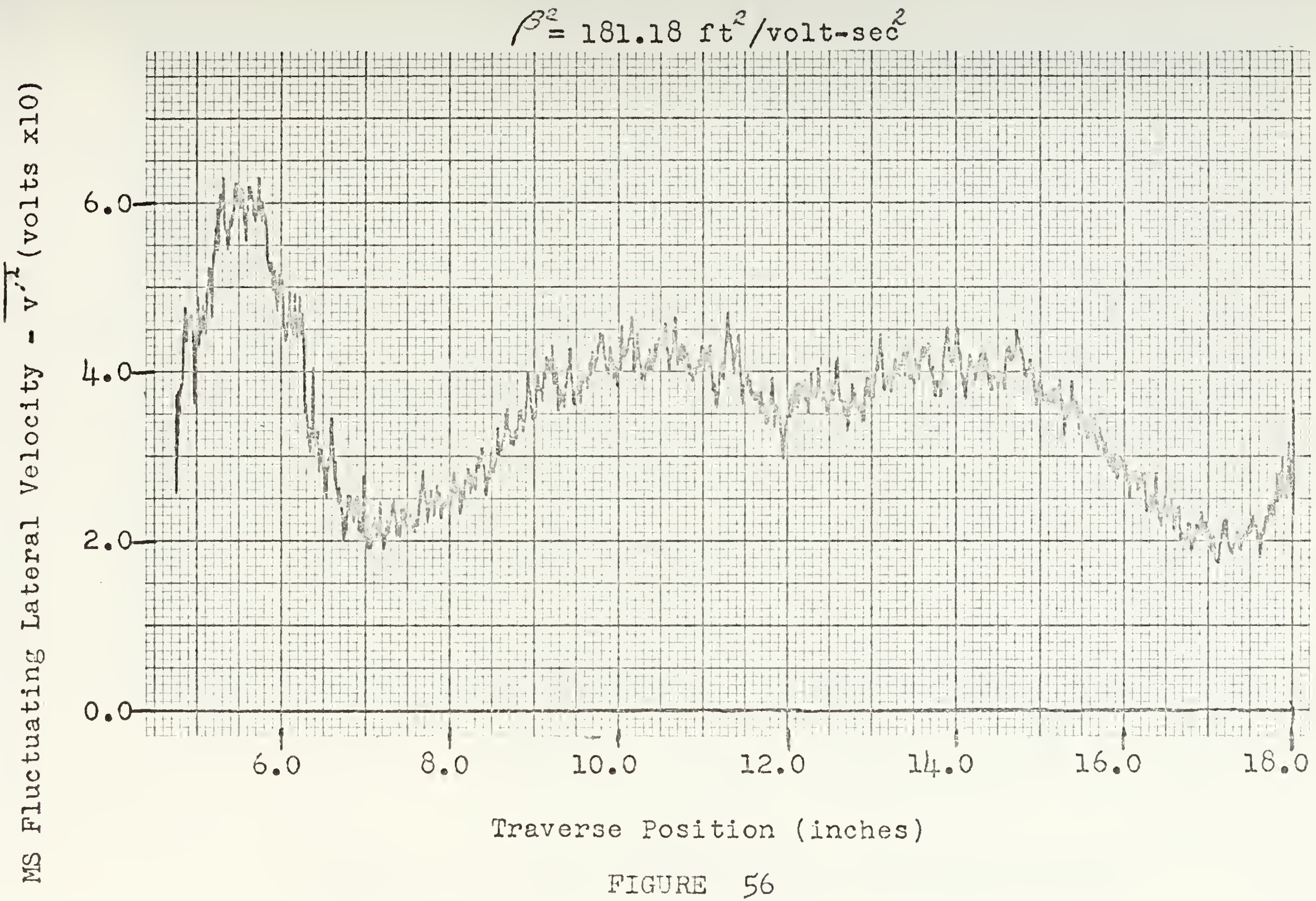


FIGURE 56
Station 6 X-Array MS Fluctuating Lateral Velocity

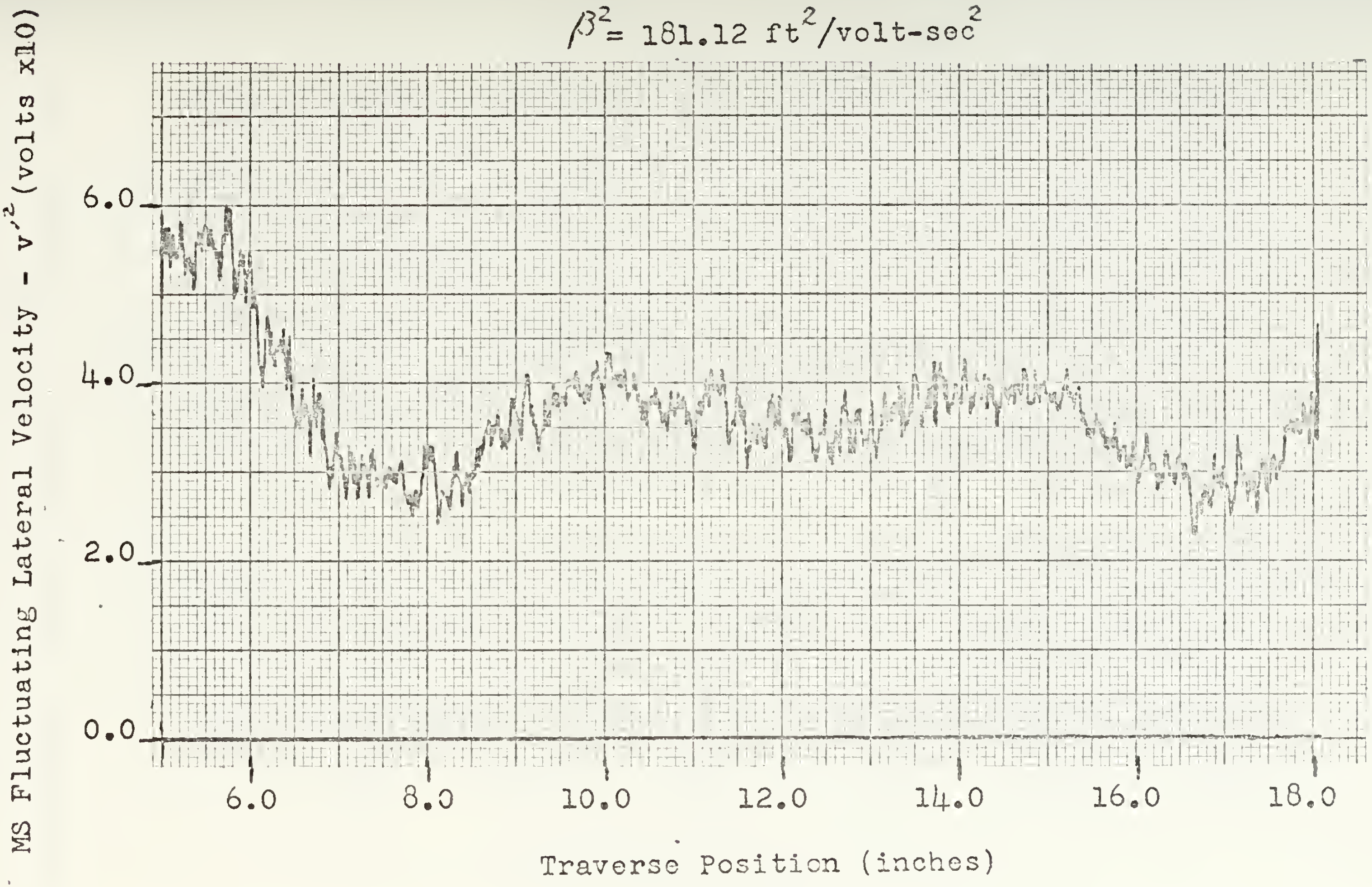


FIGURE 57
Station 7 X-Array MS Fluctuating Lateral Velocity

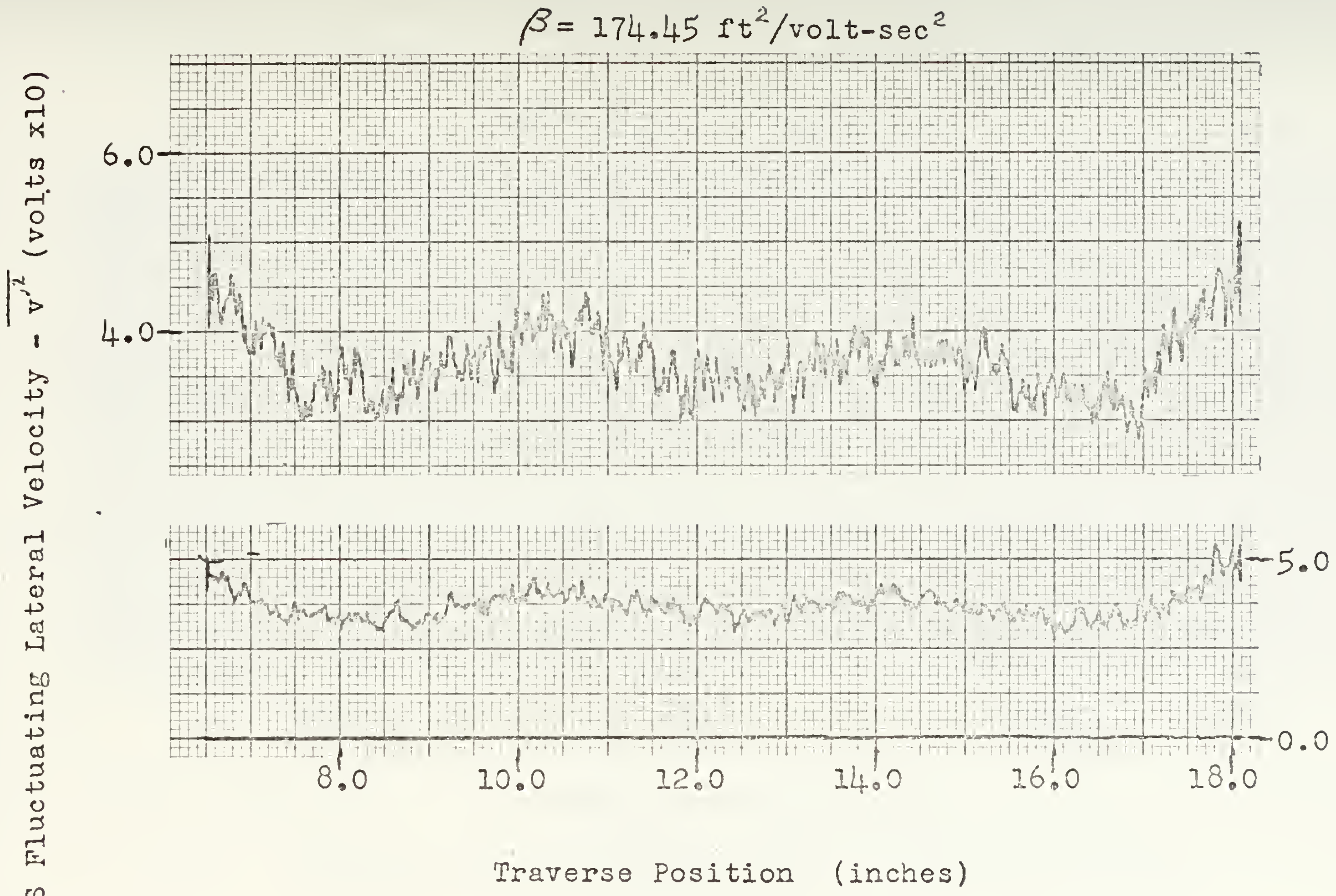


FIGURE 58
Station 8 X-Array MS Fluctuating Lateral Velocity

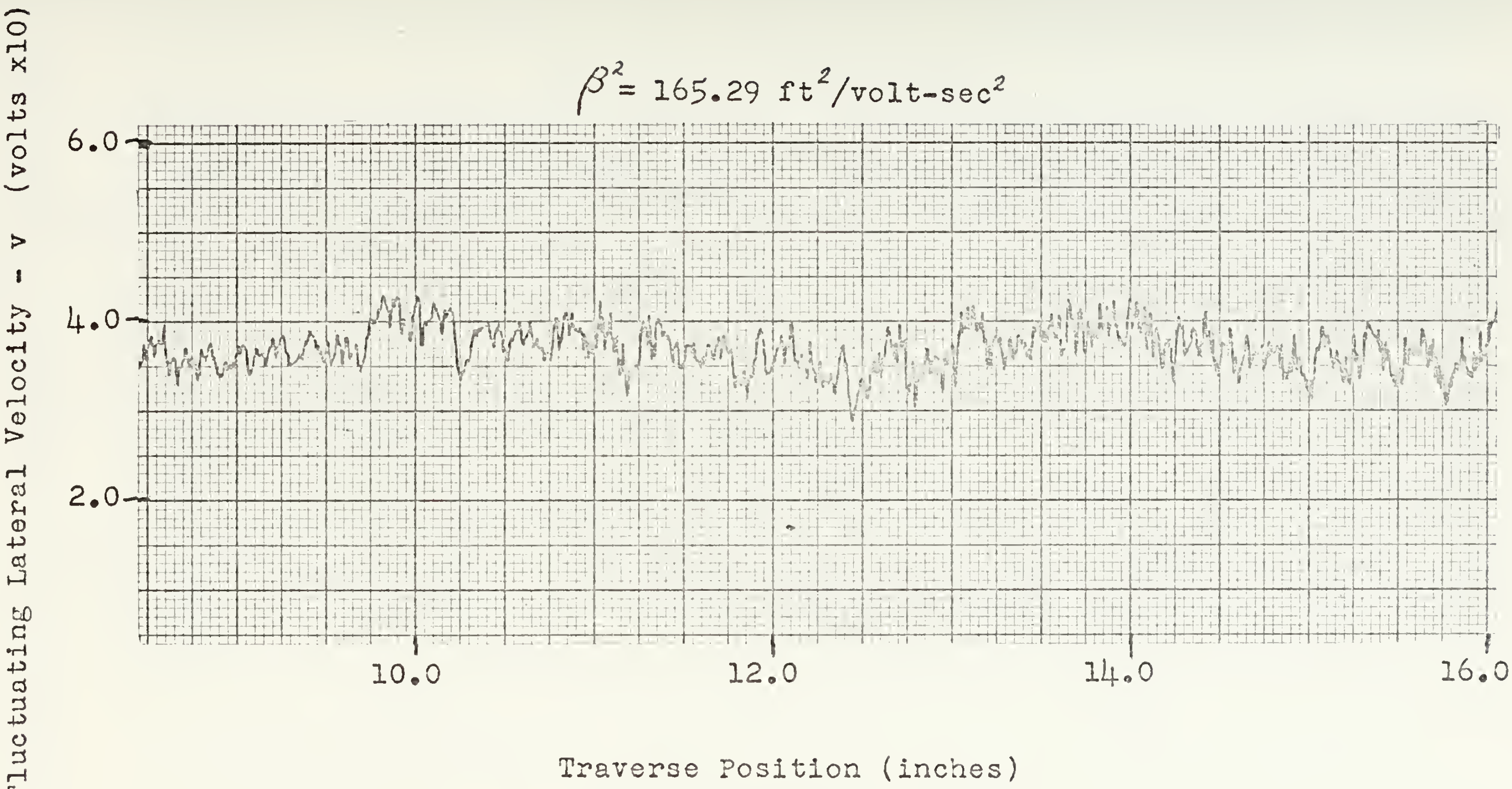
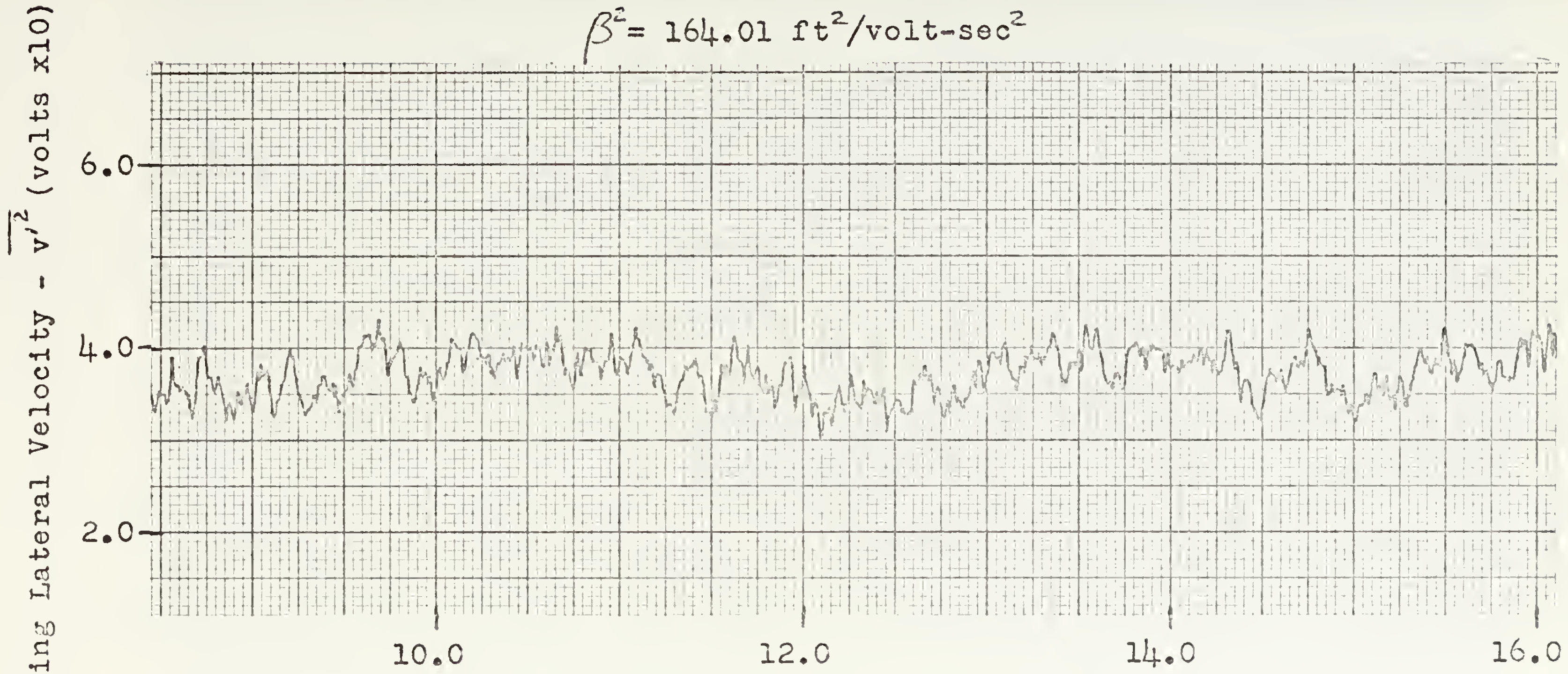


FIGURE 59
Station 9 X-Array MS Fluctuating Lateral Velocity



Traverse Position (inches)

FIGURE 60

Station 10 X-Array MS Fluctuating Lateral Velocity

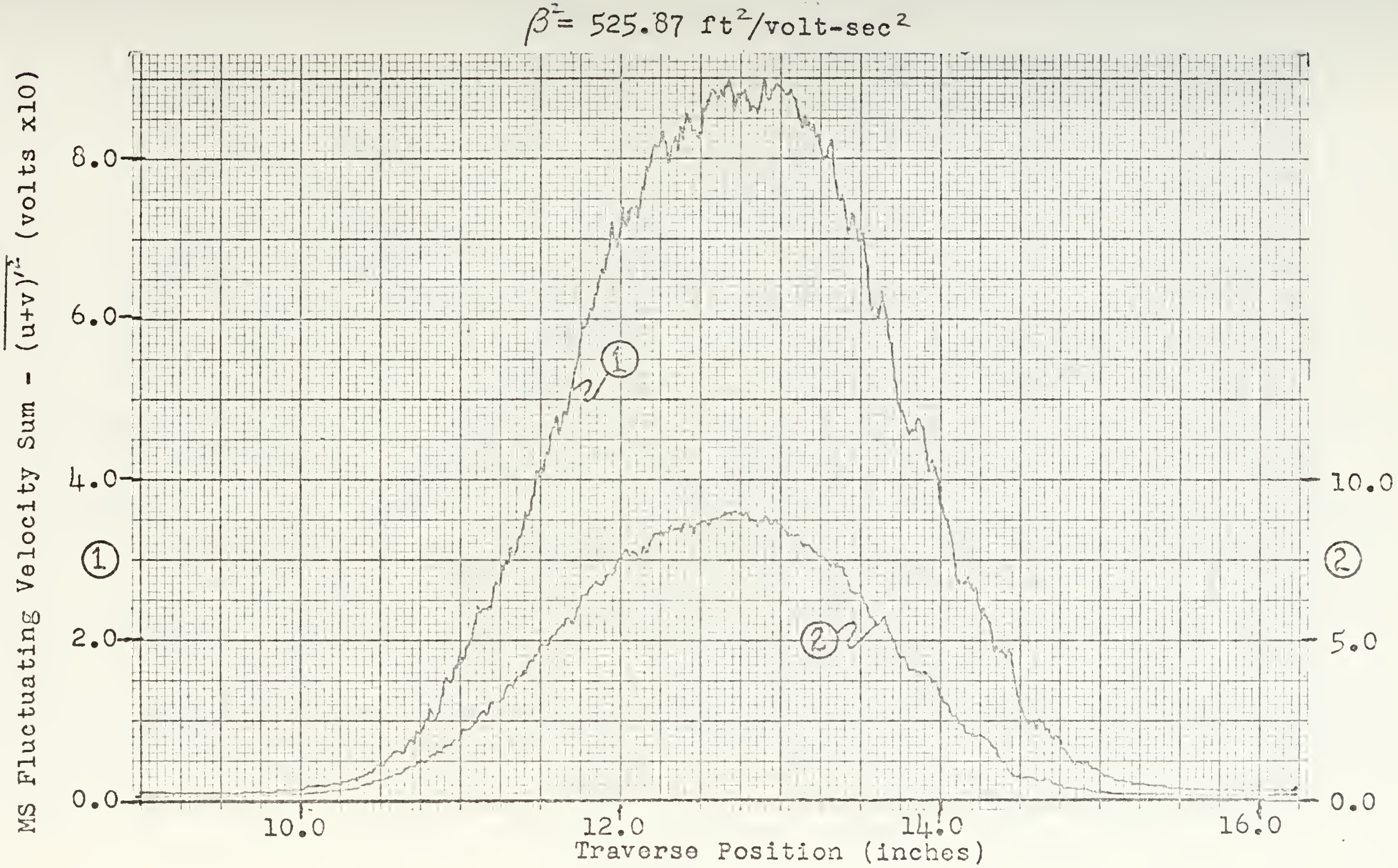


FIGURE 61

Station 1 X-Array MS Fluctuating Velocity Sum

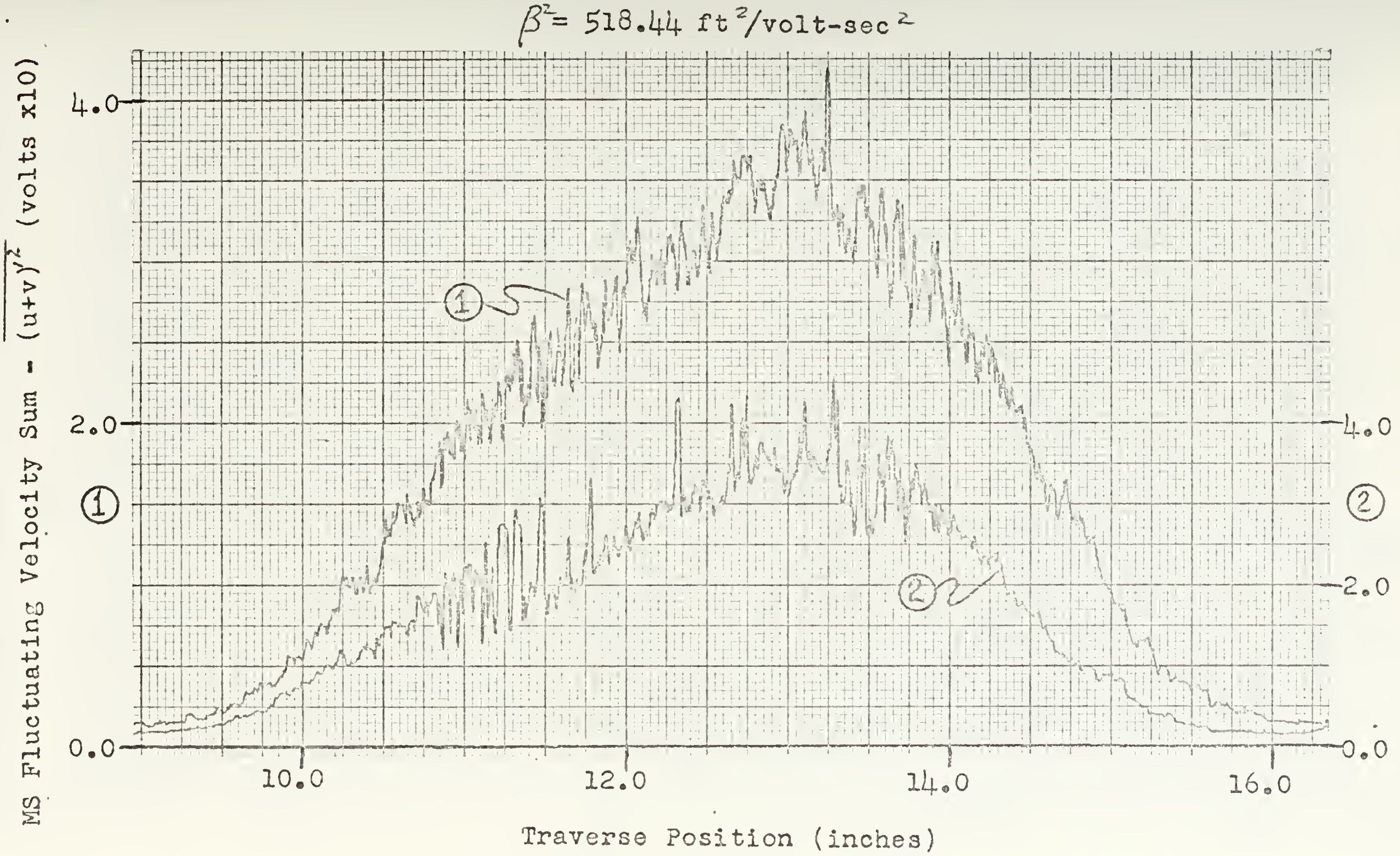


FIGURE 62

Station 2 X-Array MS Fluctuating Velocity Sum

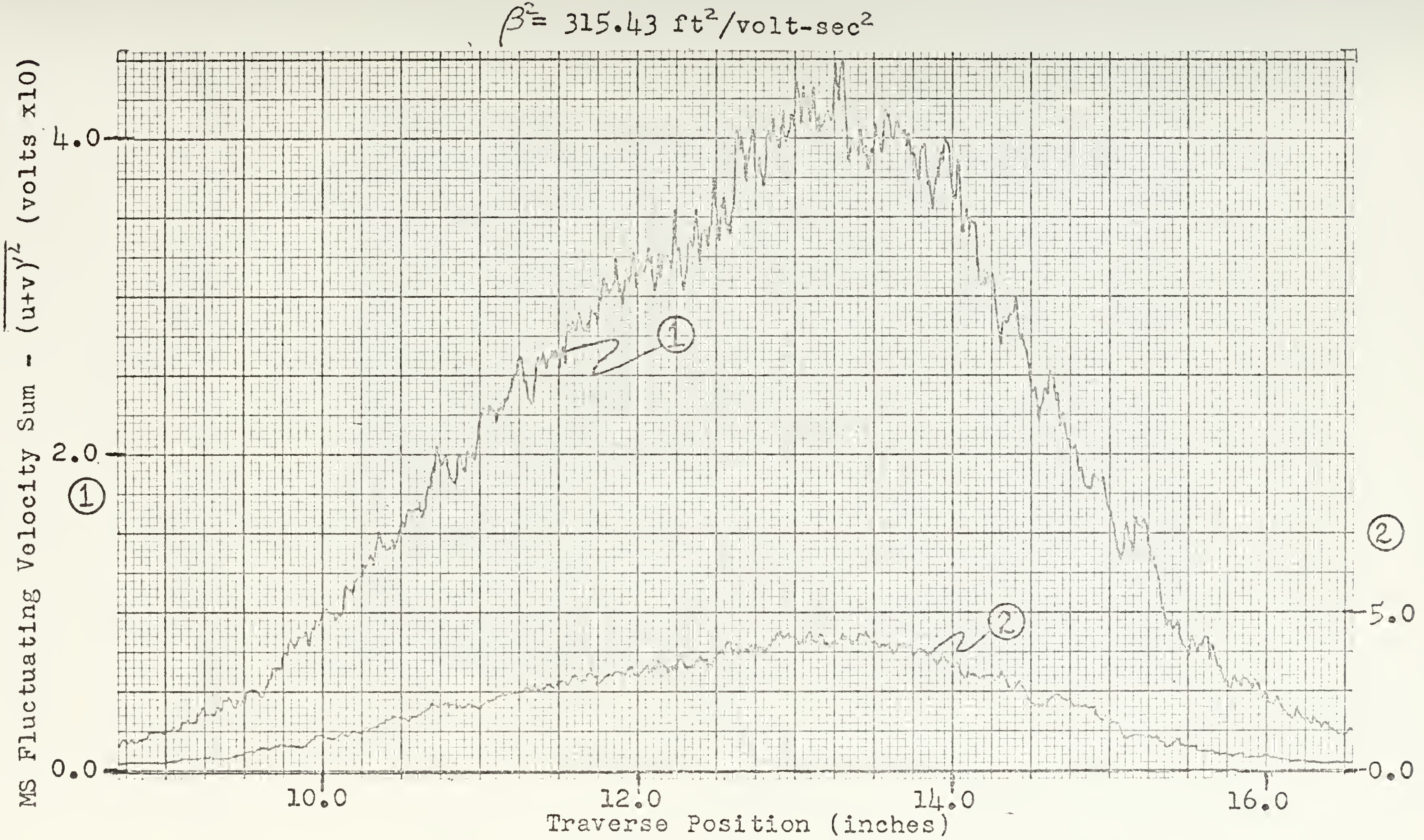


FIGURE 63

Station 3 X-Array MS Fluctuating Velocity Sum

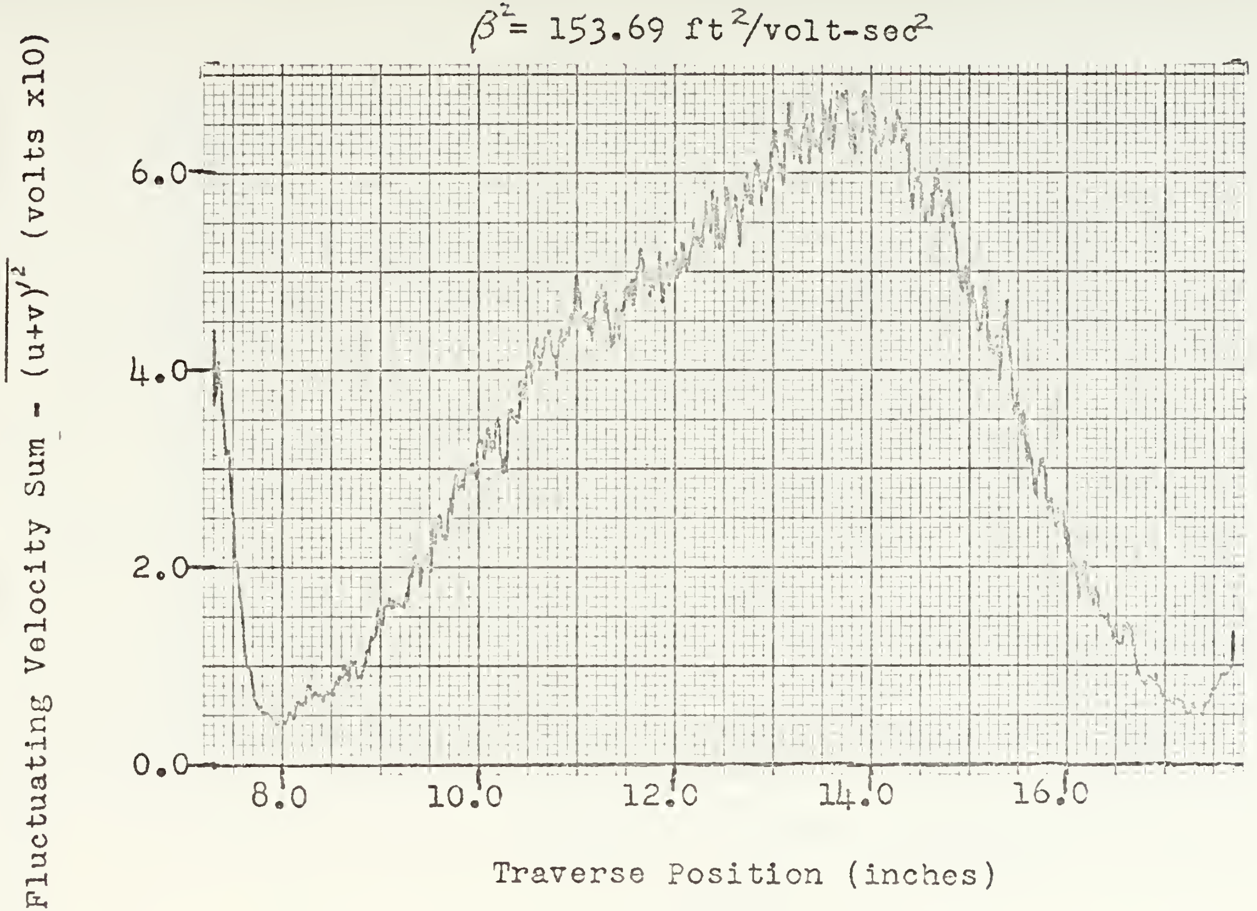


FIGURE 64

Station 4 X-Array MS Fluctuating Velocity Sum

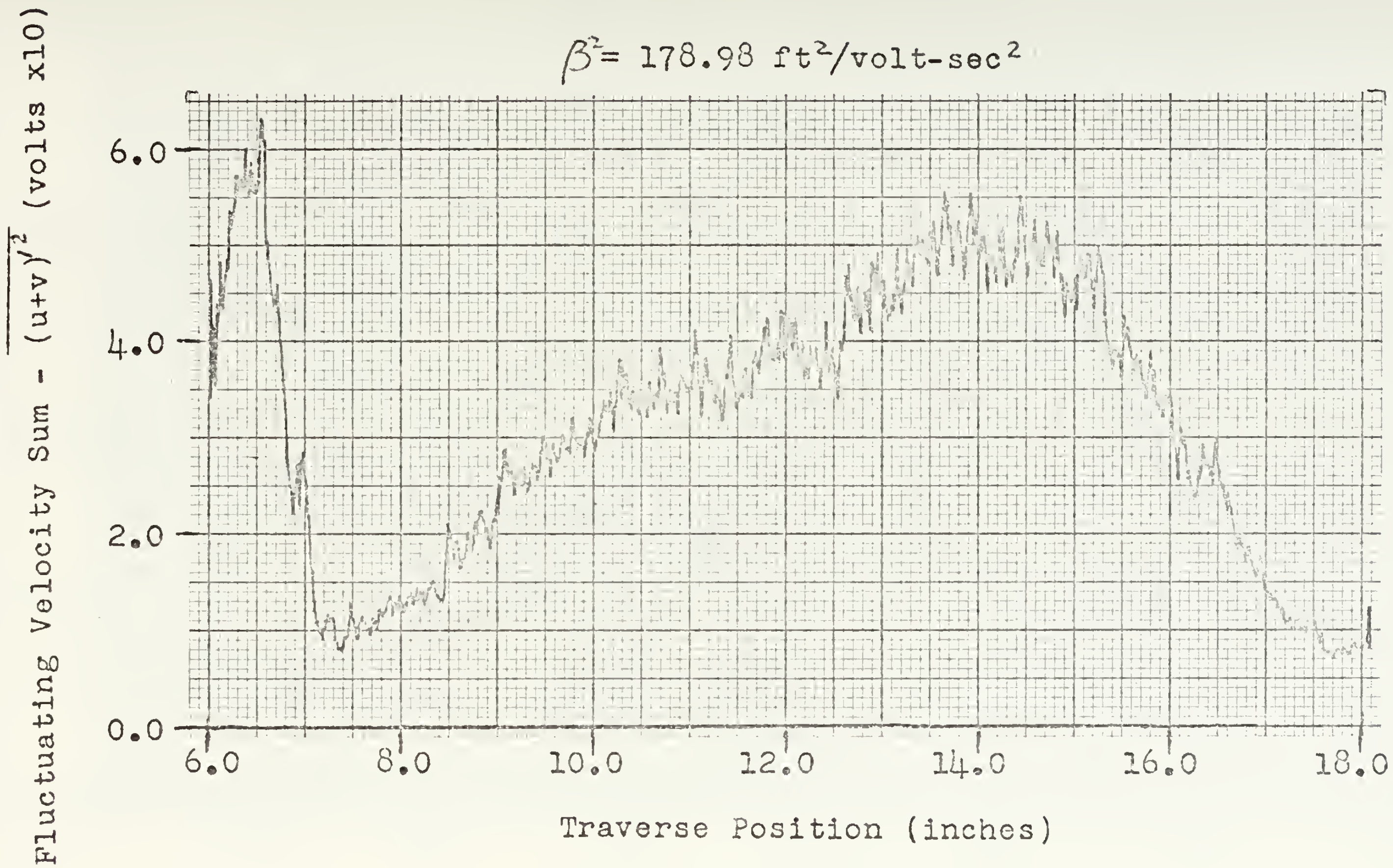


FIGURE 65

Station 5 X-Array MS Fluctuating Velocity Sum

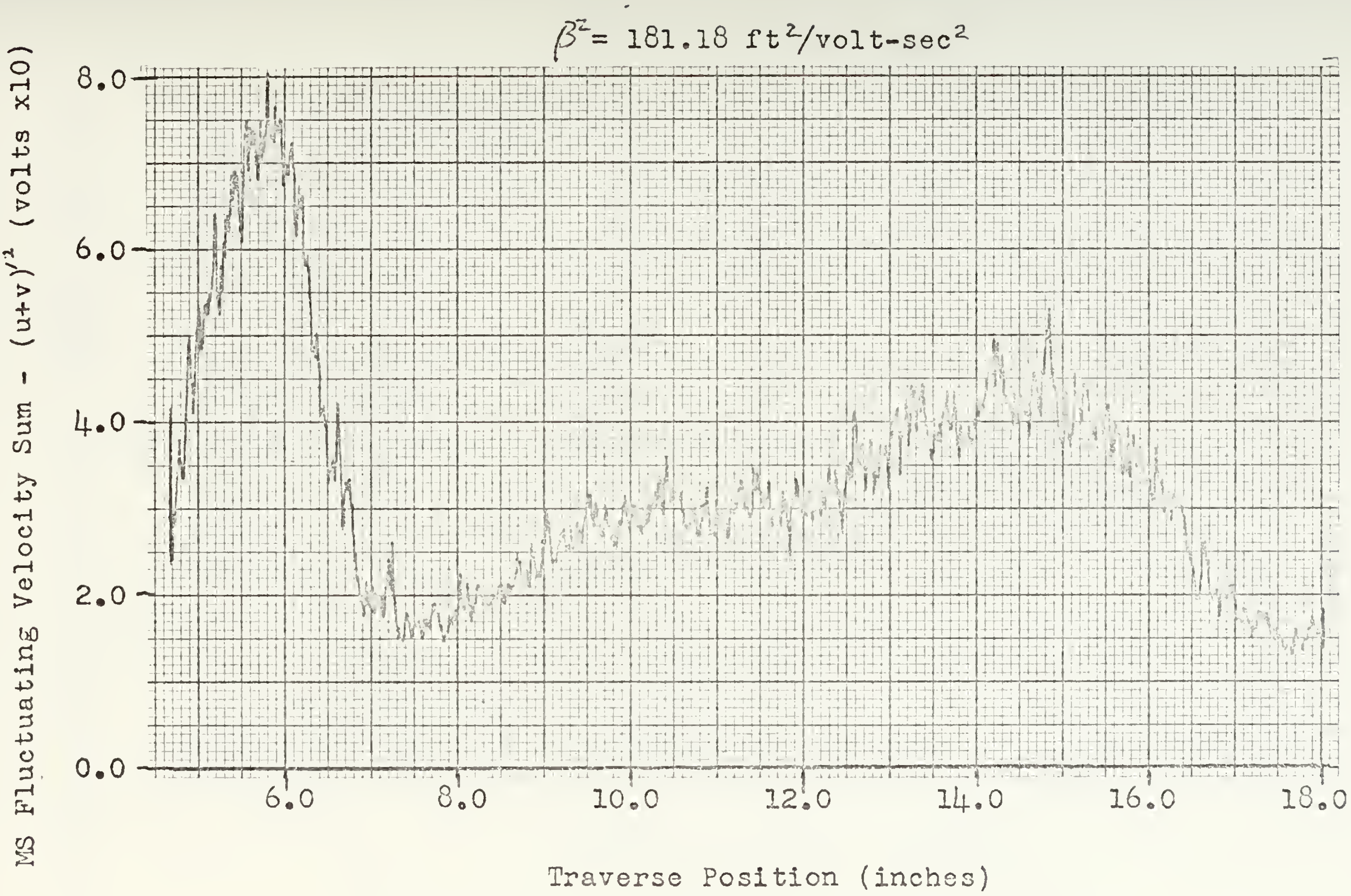


FIGURE 66

Station 6 X-Array MS Fluctuating Velocity Sum

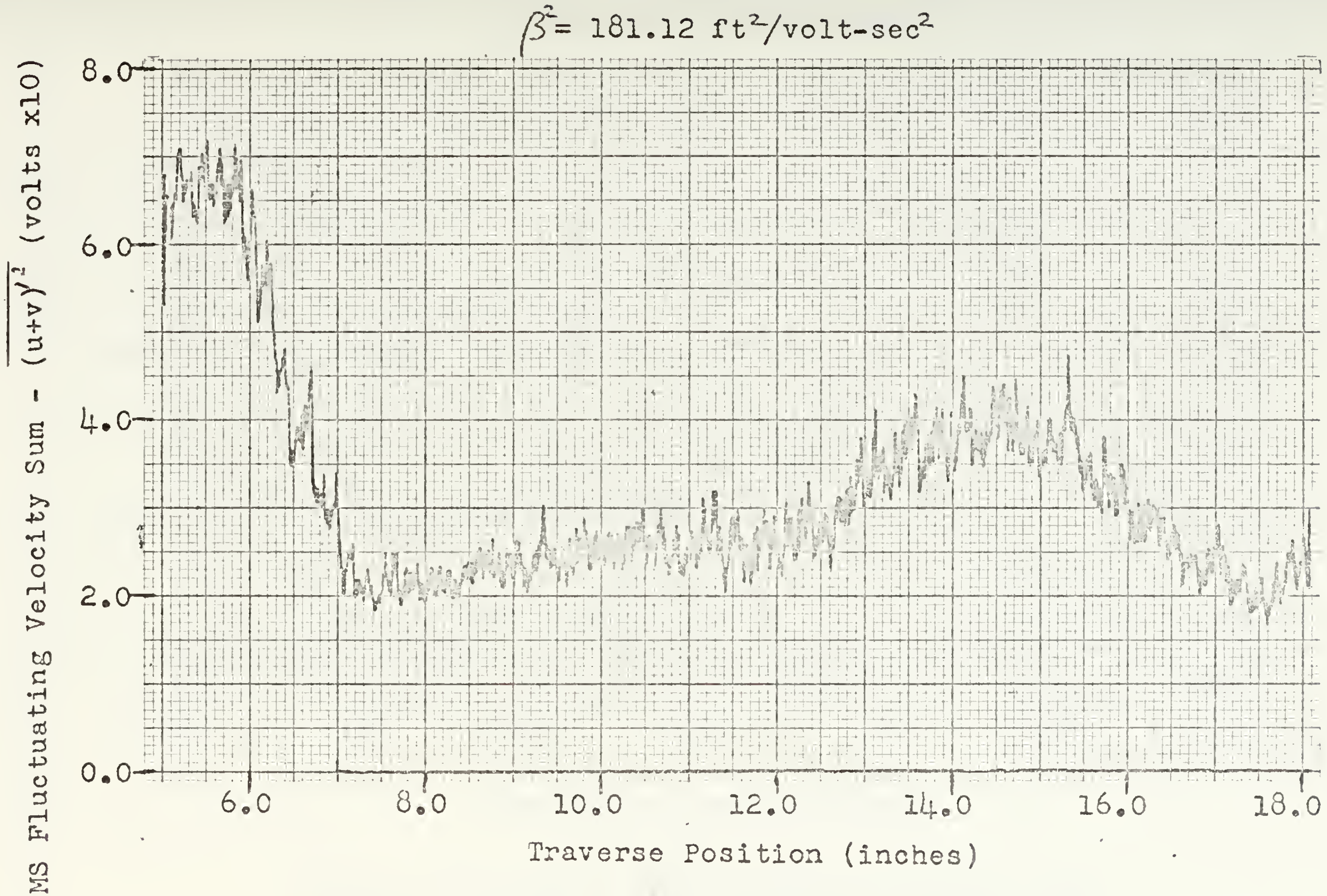


FIGURE 67

Station 7 X-Array MS Fluctuating Velocity Sum

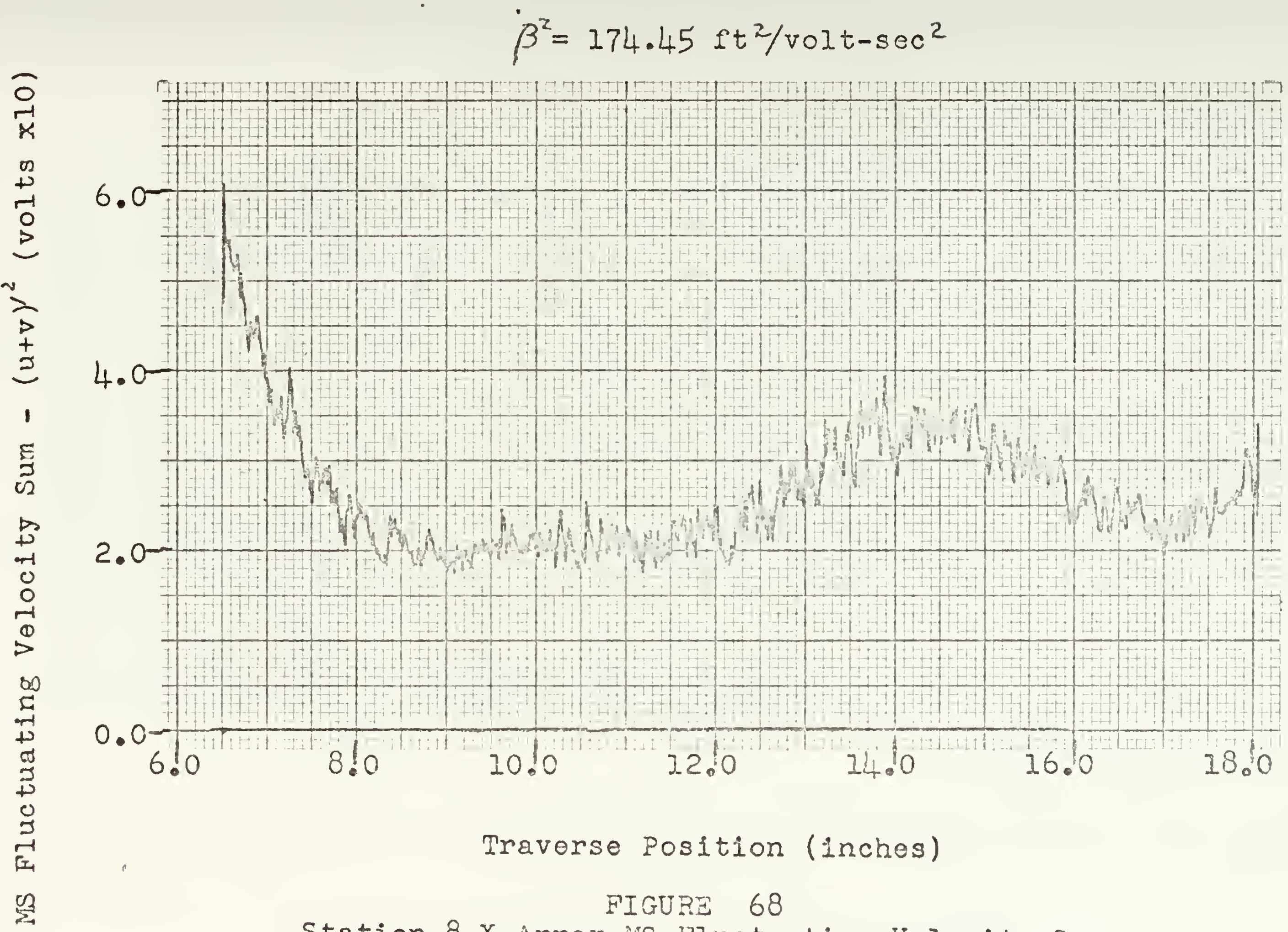


FIGURE 68
Station 8 X-Array MS Fluctuating Velocity Sum

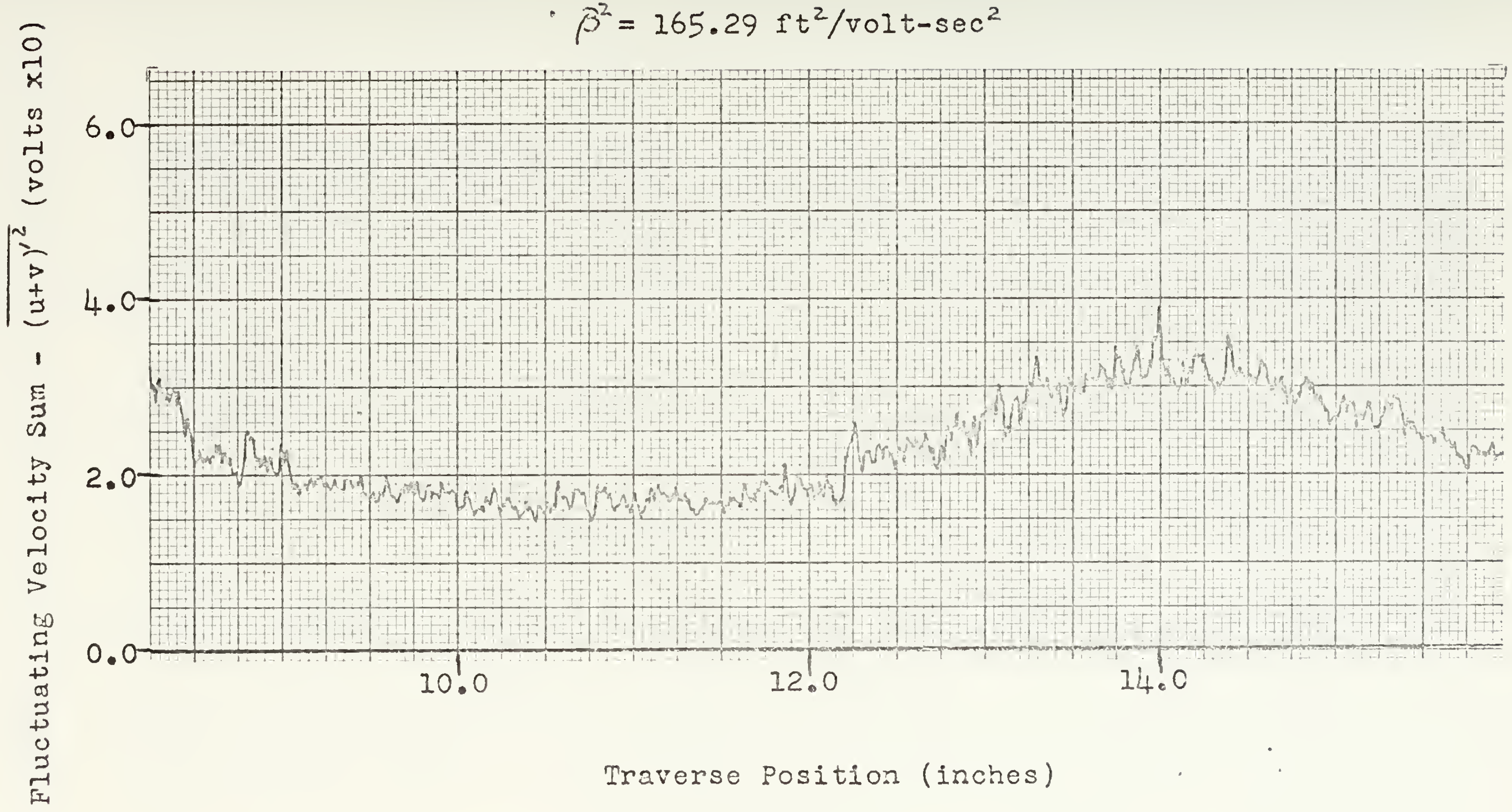


FIGURE 69
Station 9 X-Array MS Fluctuating Velocity Sum

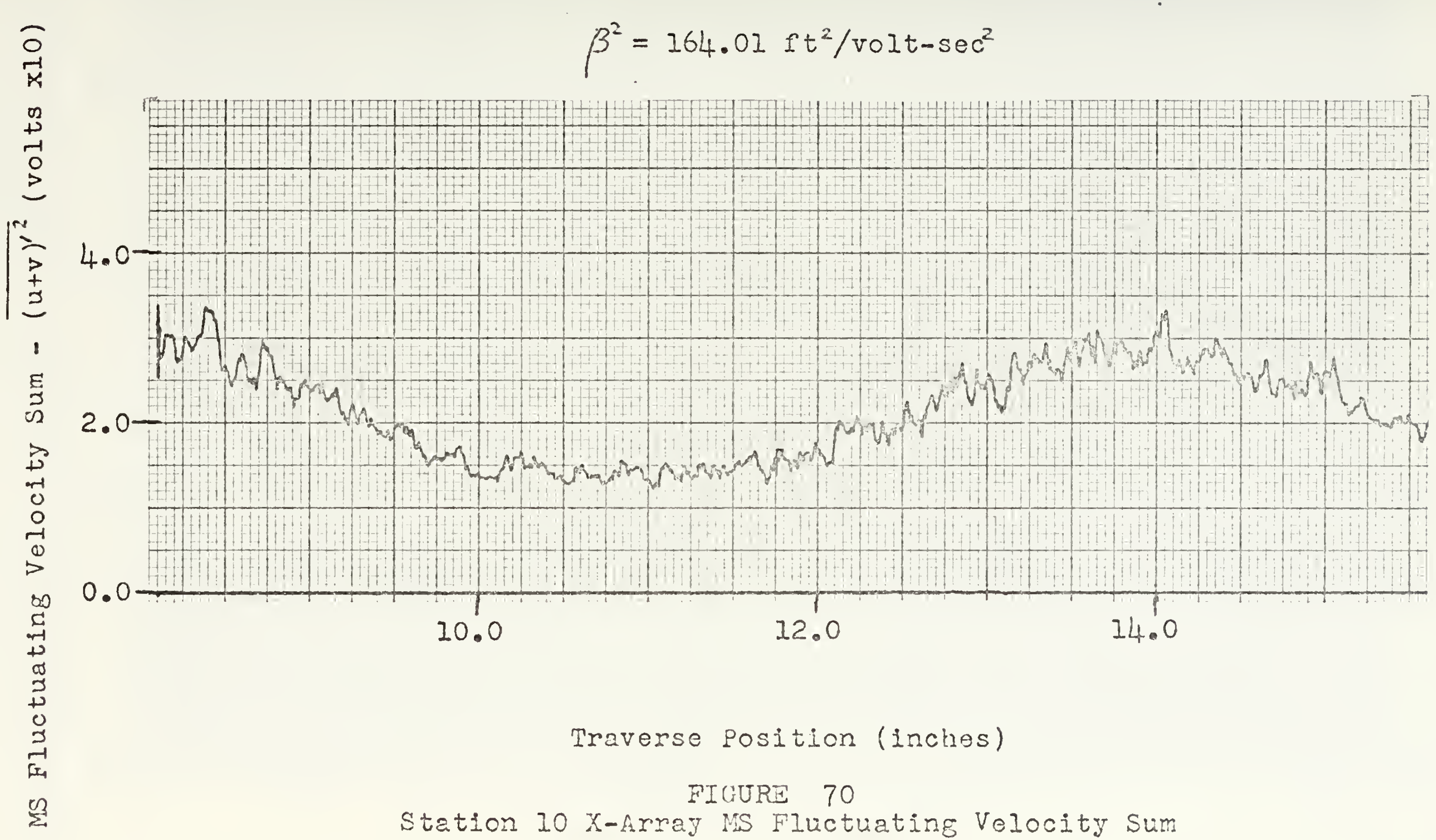


FIGURE 70
Station 10 X-Array MS Fluctuating Velocity Sum

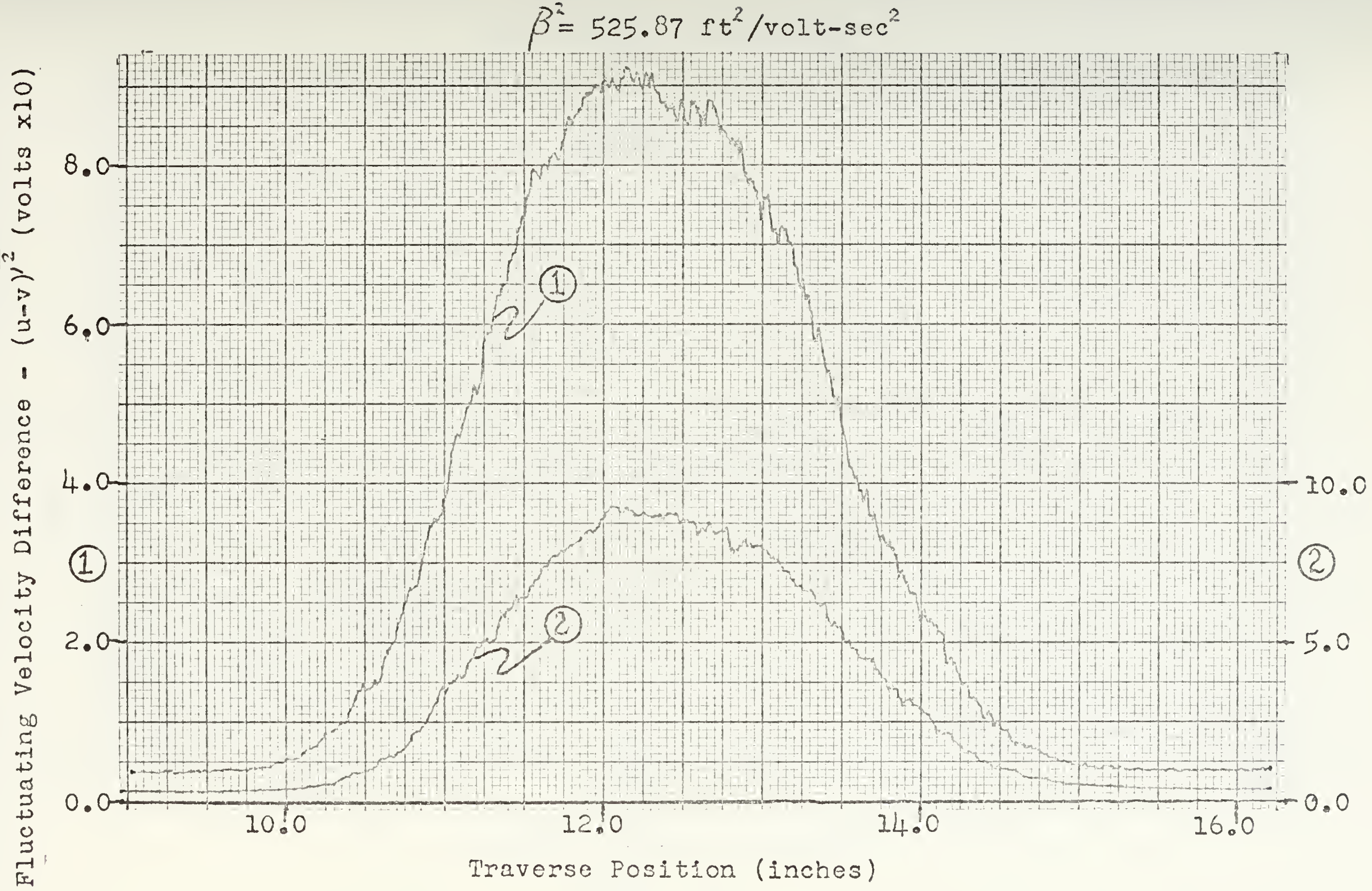


FIGURE 71
Station 1 X-Array MS Fluctuating Velocity Difference

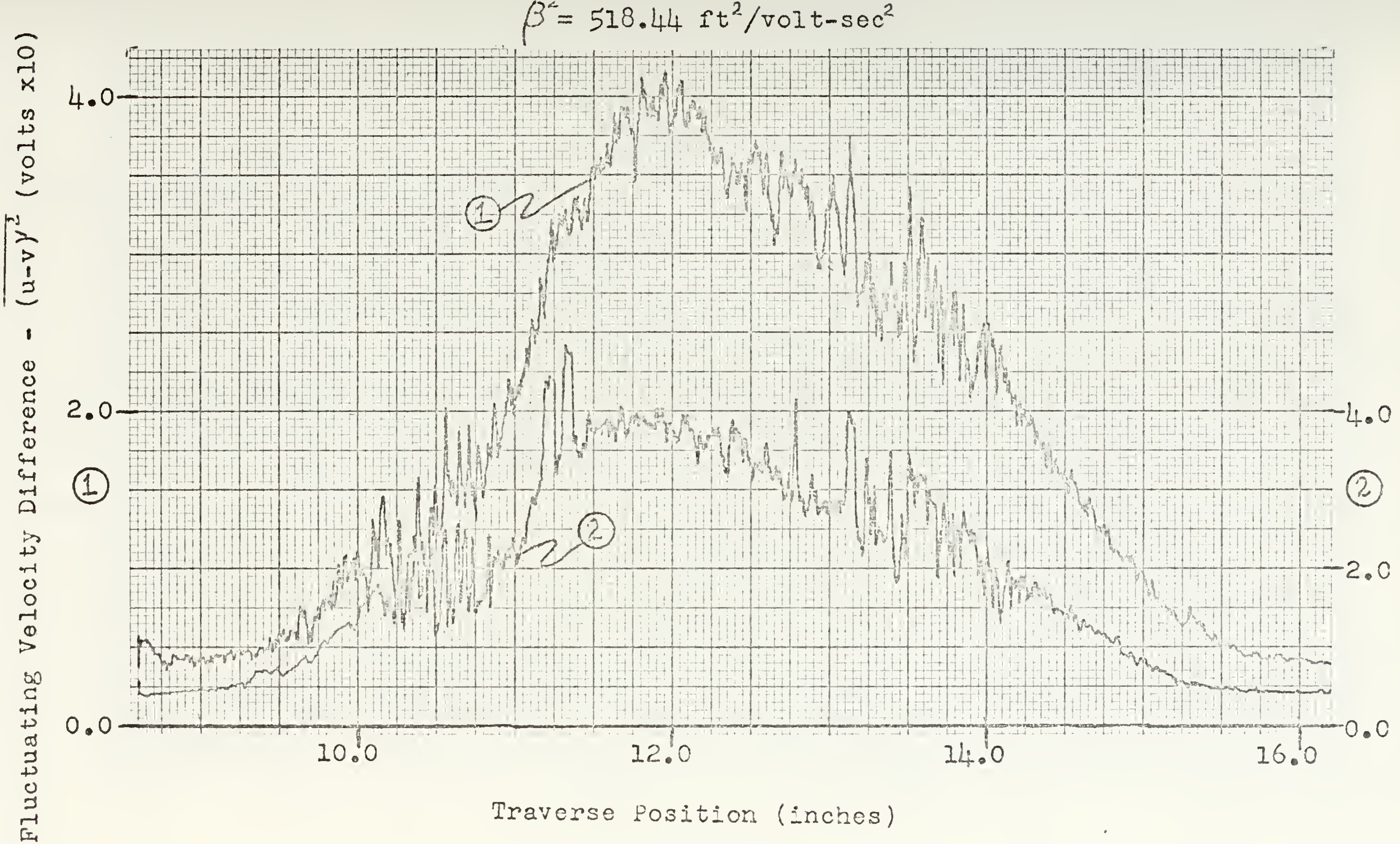


FIGURE 72
Station 2 X-Array MS Fluctuating Velocity Difference

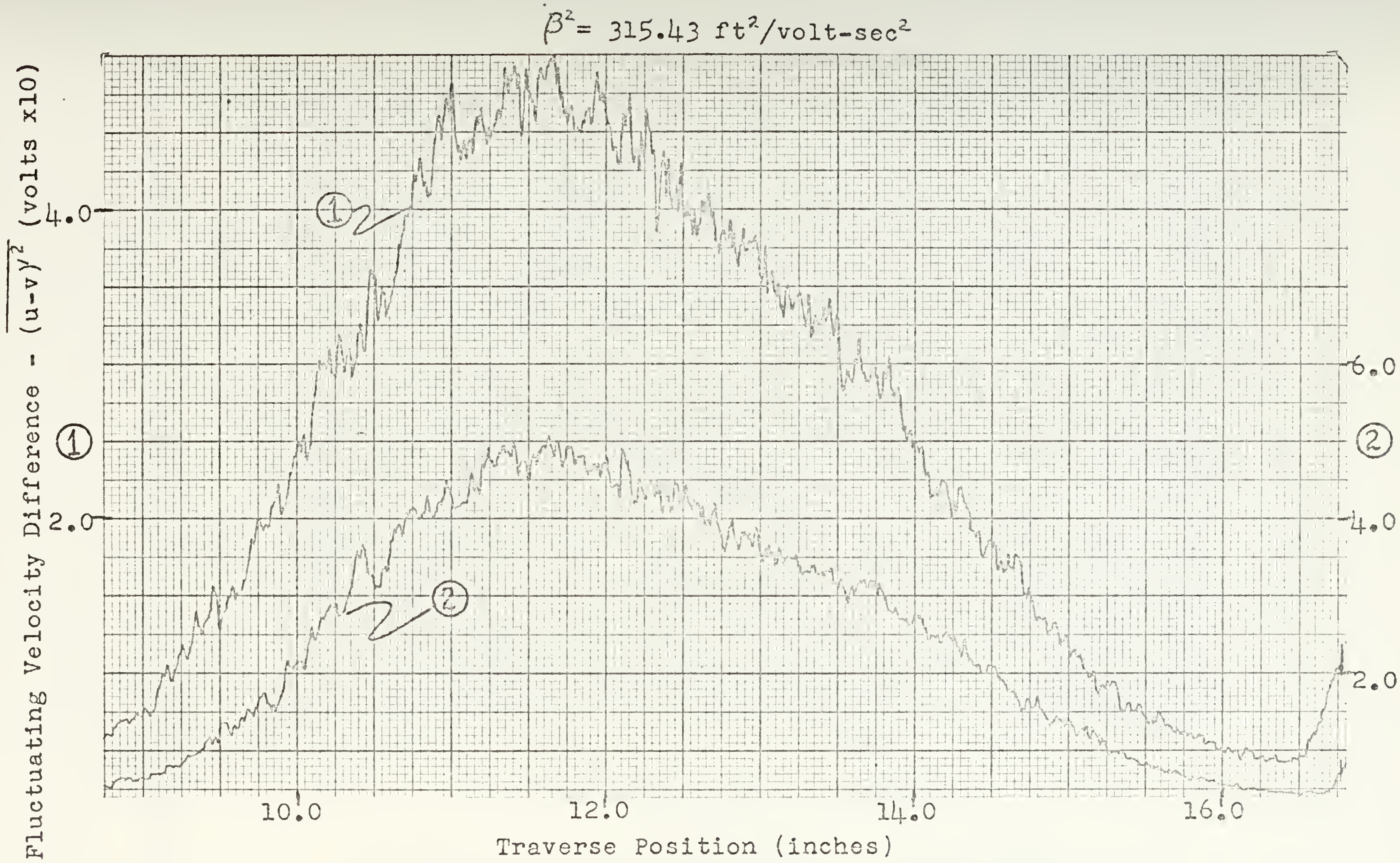


FIGURE 73
Station 3 X-Array MS Fluctuating Velocity Difference

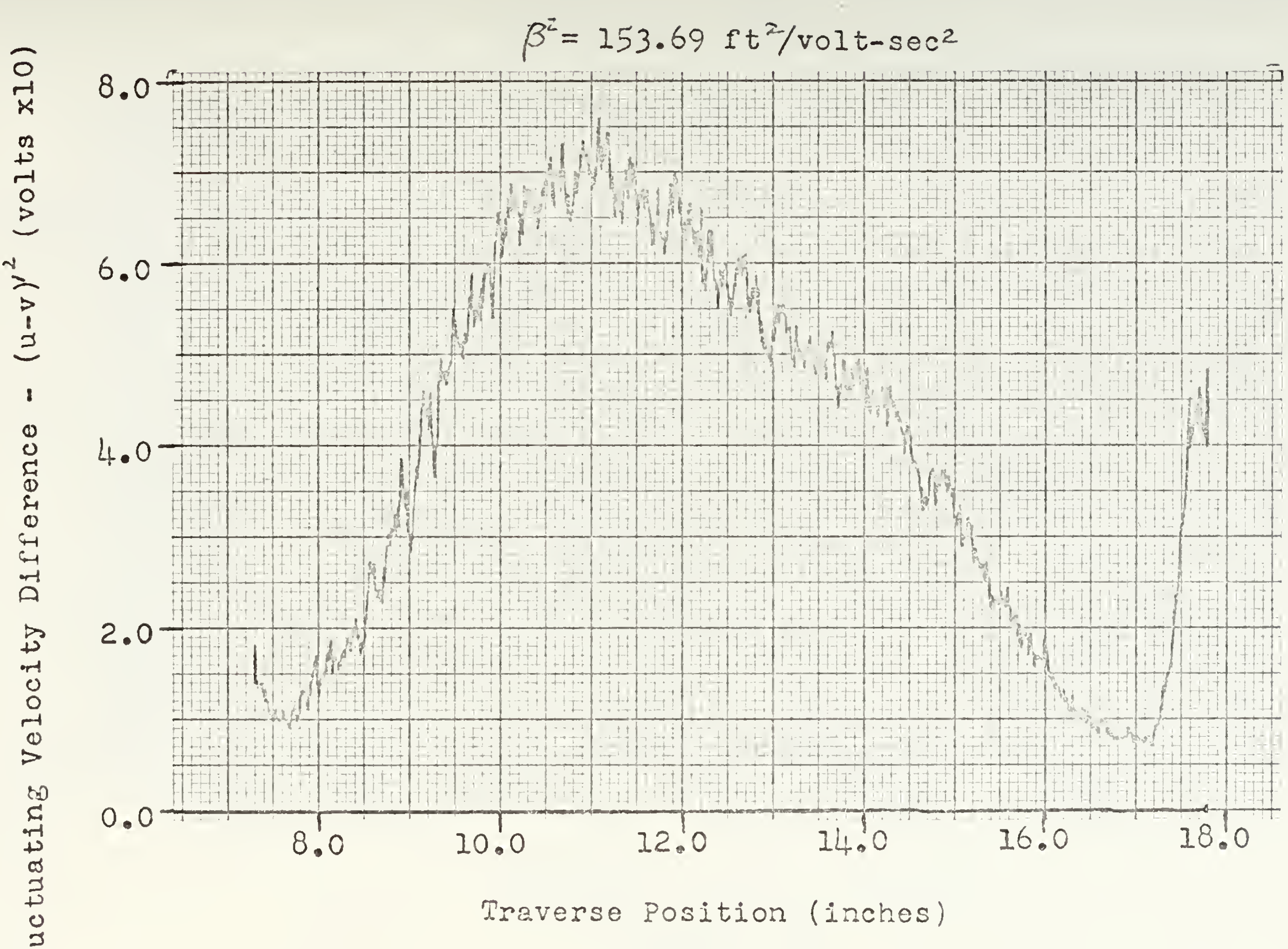


FIGURE 74
Station 4 X-Array MS Fluctuating Velocity Difference

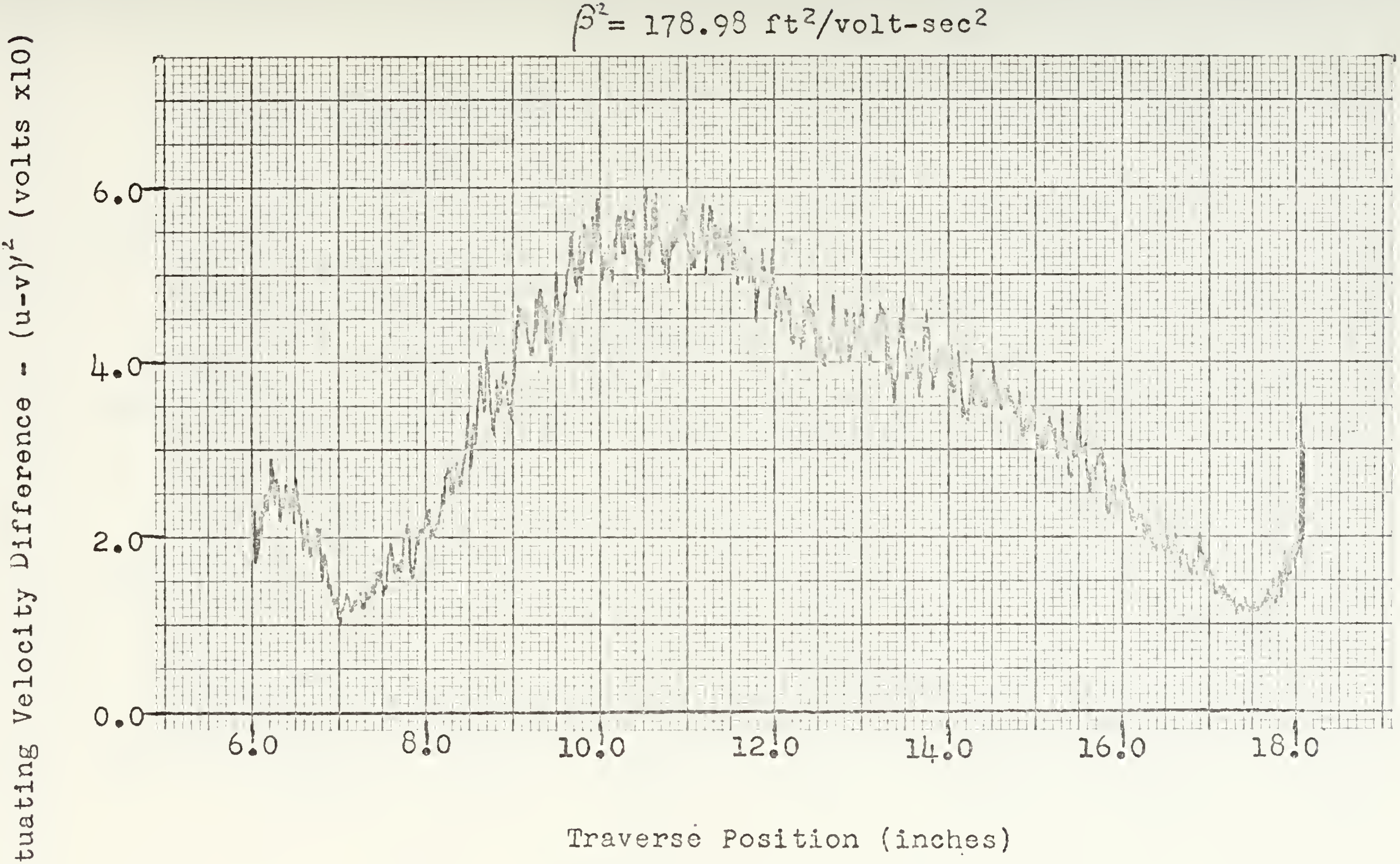
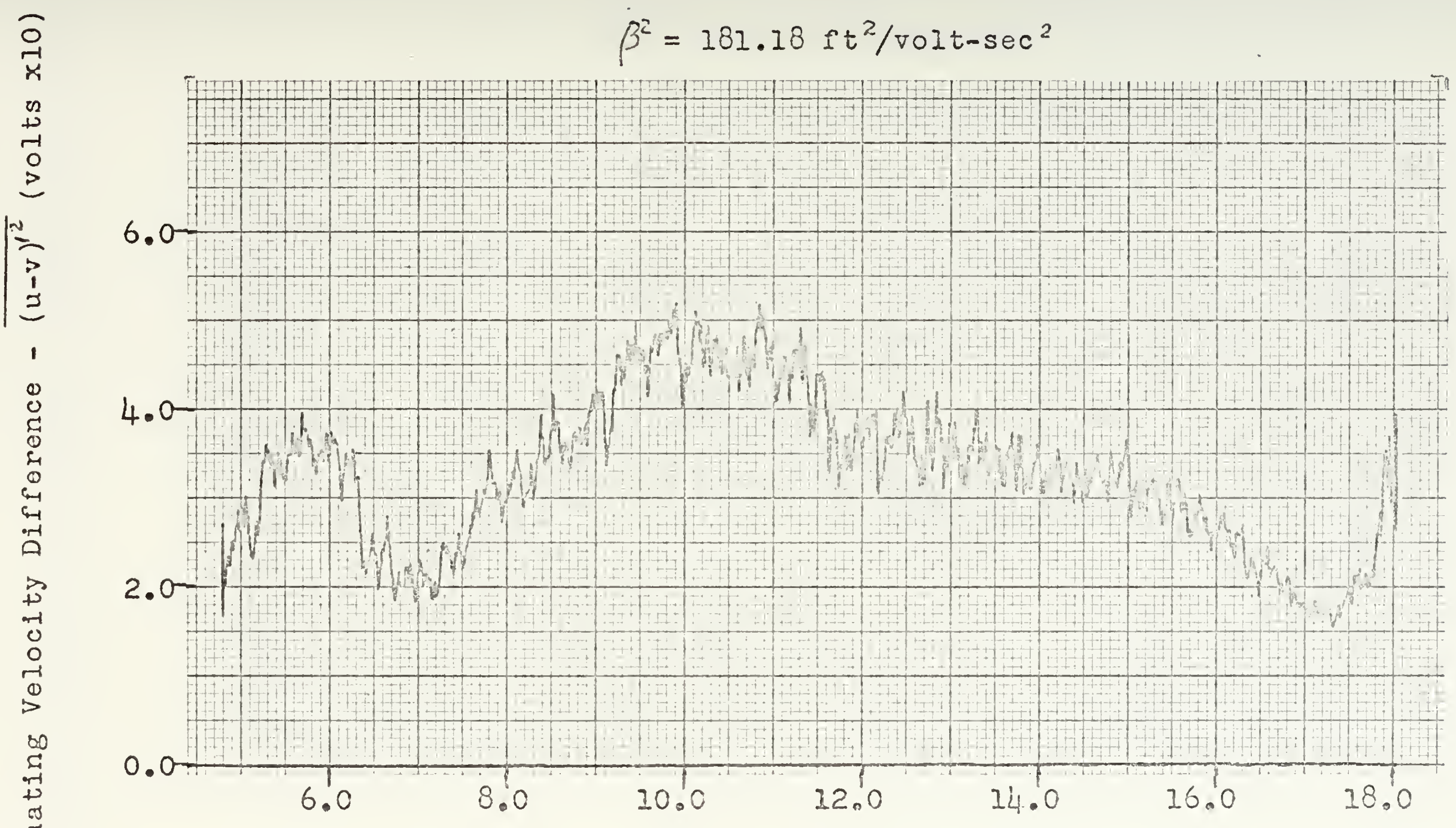


FIGURE 75
Station 5 X-Array MS Fluctuating Velocity Difference



Traverse Position (inches)

FIGURE 76
Station 6 X-Array MS Fluctuating Velocity Difference

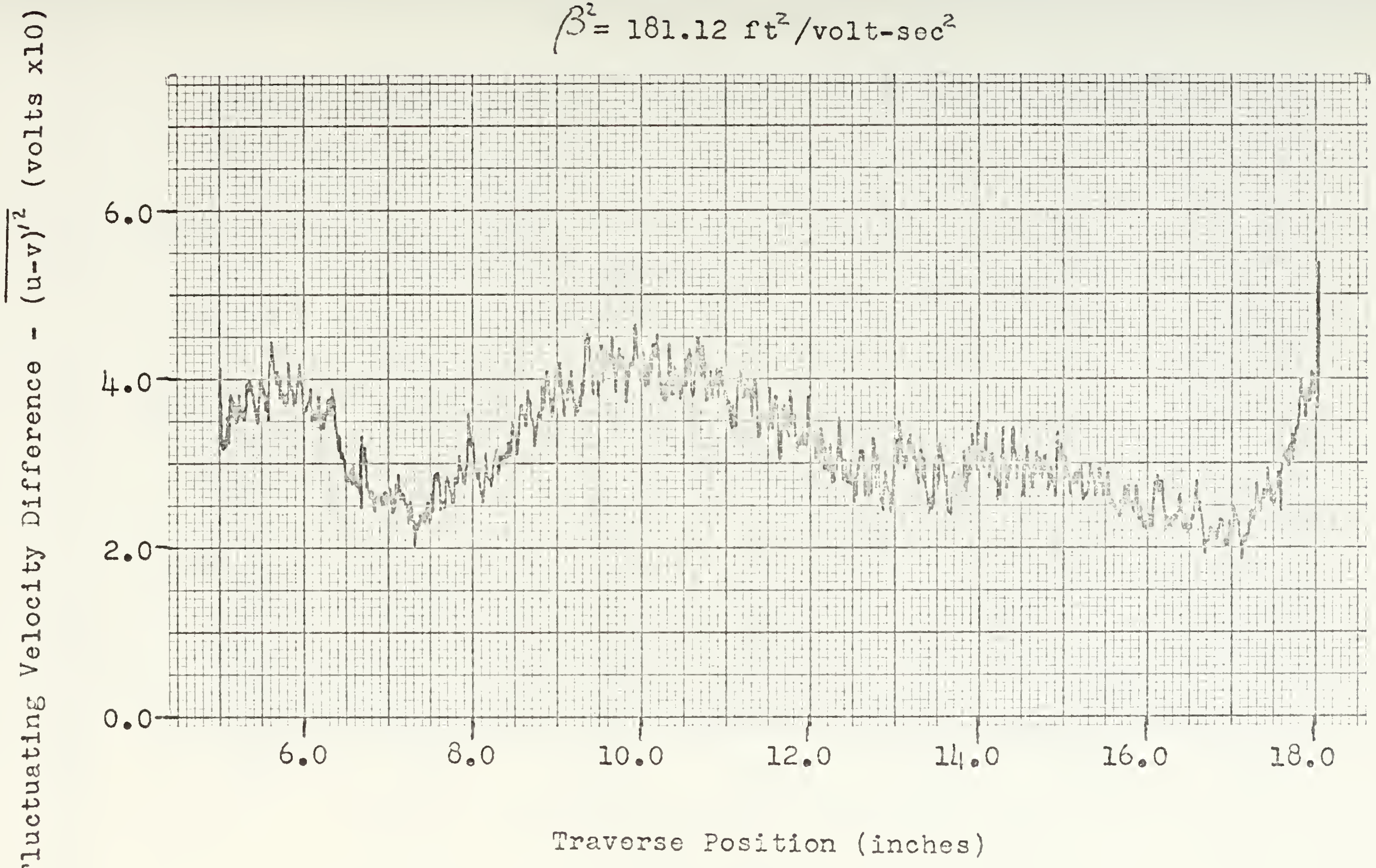


FIGURE 77
Station 7 X-Array MS Fluctuating Velocity Difference

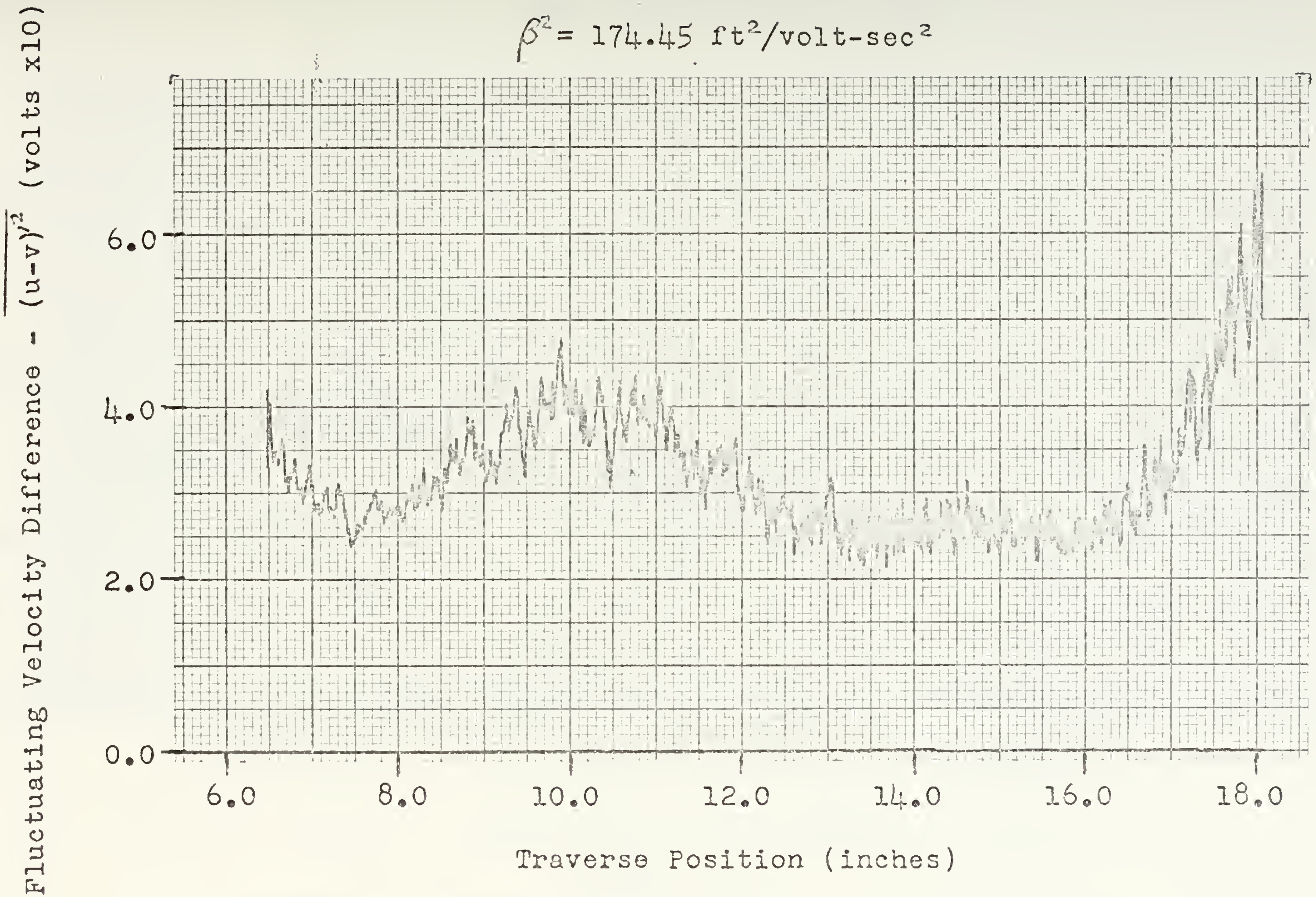


FIGURE 78
Station 8 X-Array MS Fluctuating Velocity Difference

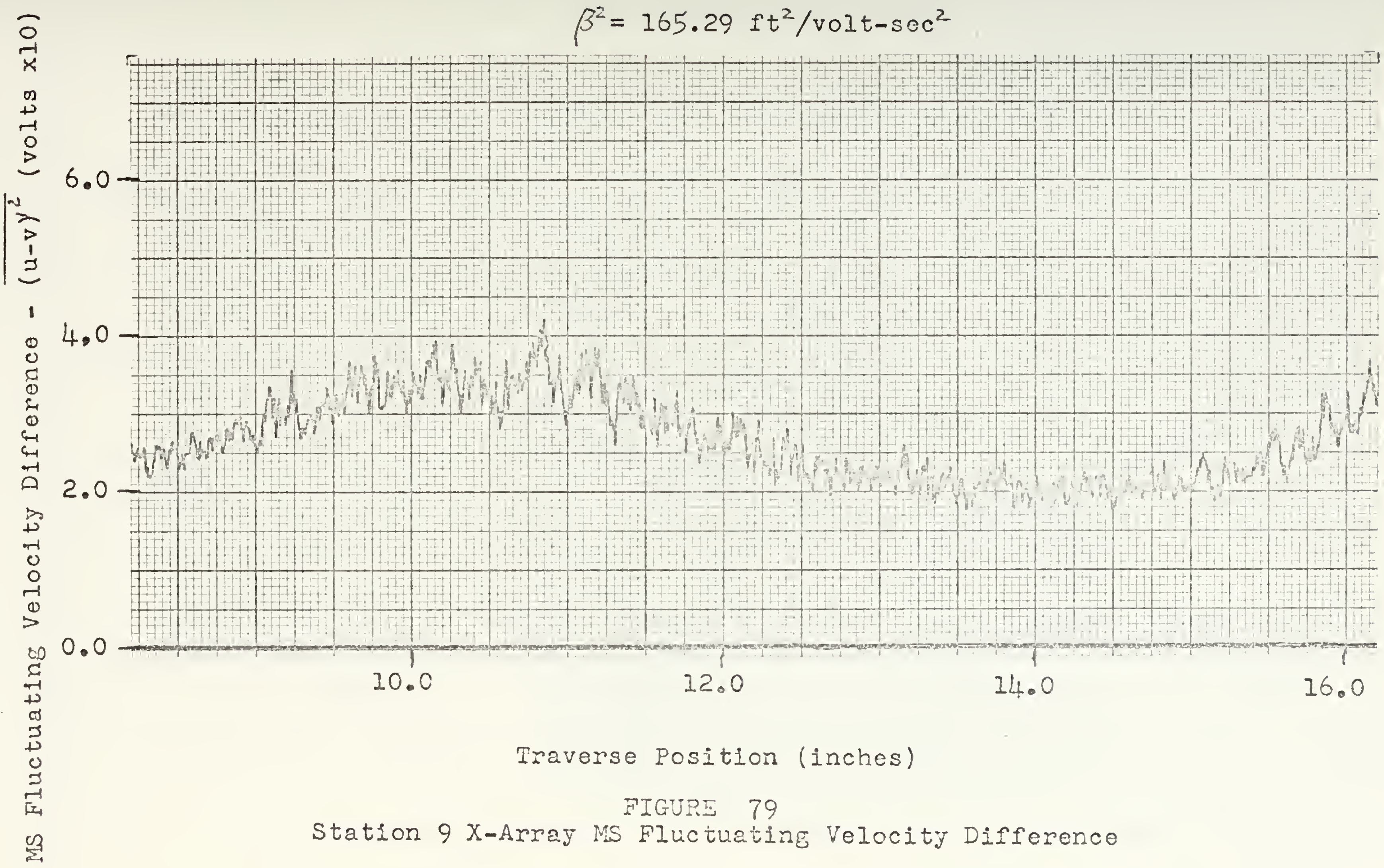


FIGURE 79
Station 9 X-Array MS Fluctuating Velocity Difference

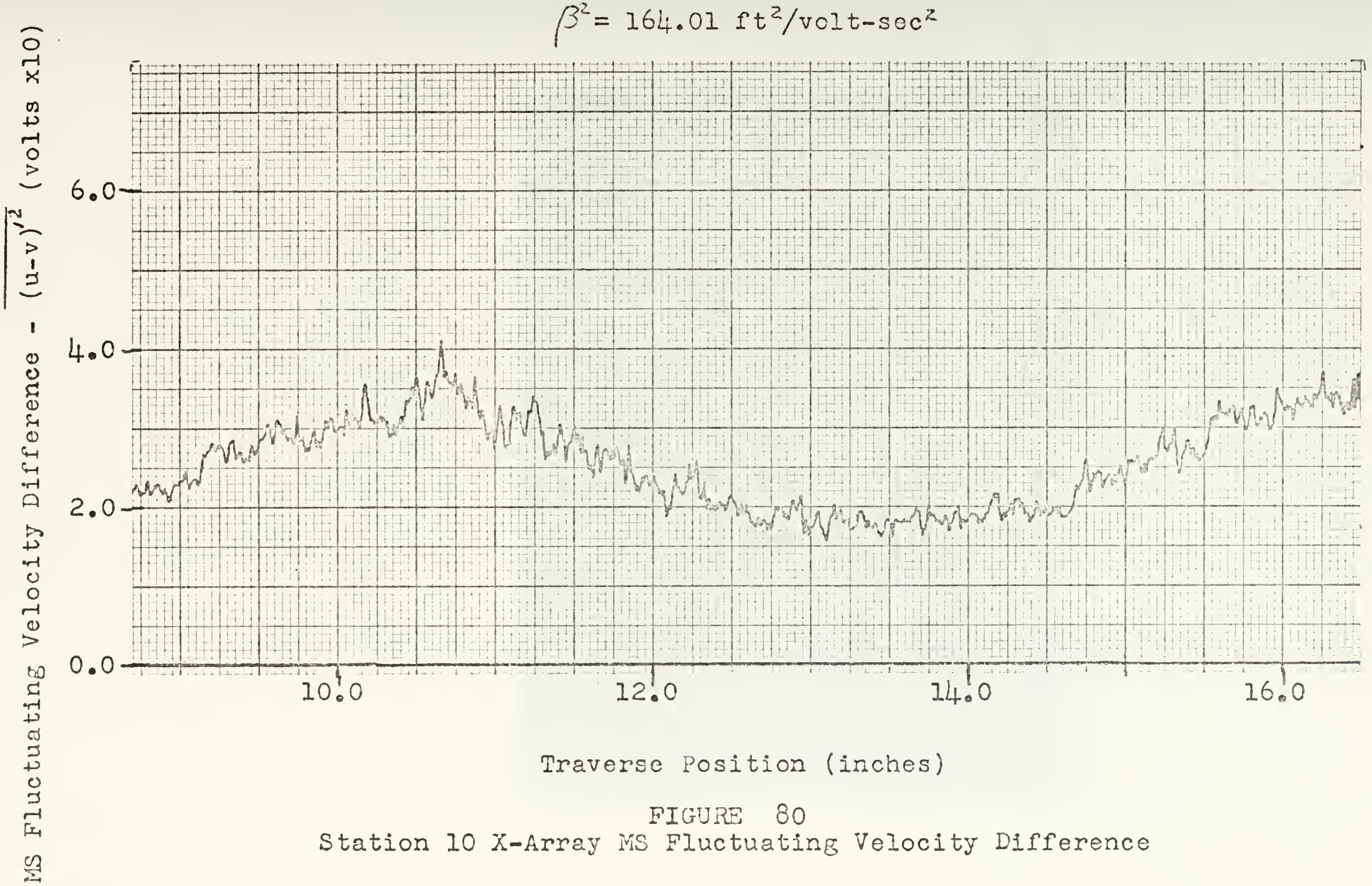


FIGURE 80
Station 10 X-Array MS Fluctuating Velocity Difference

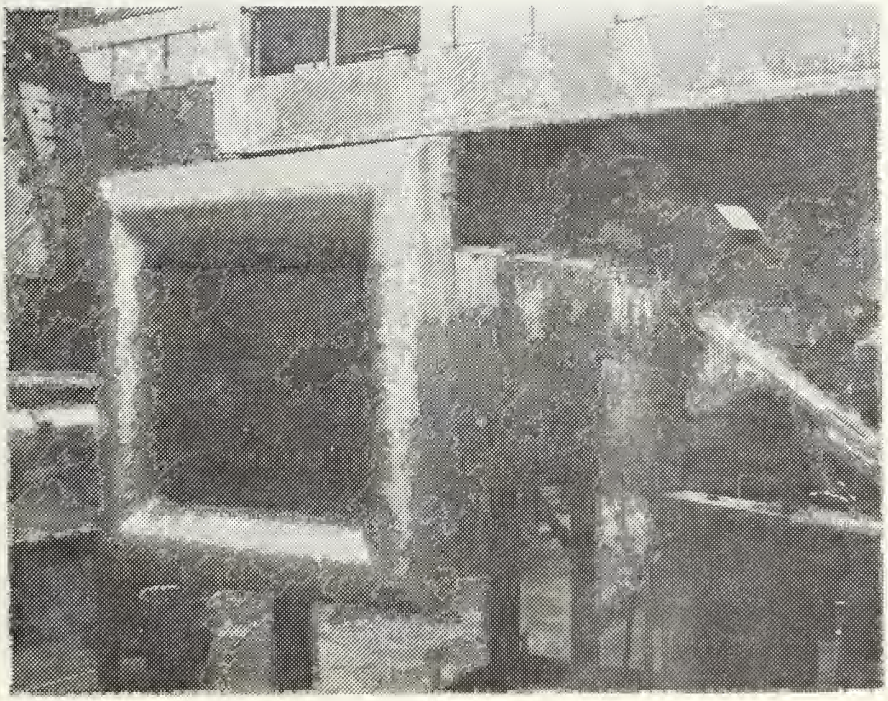


FIGURE 81

The wind Tunnel Inlet

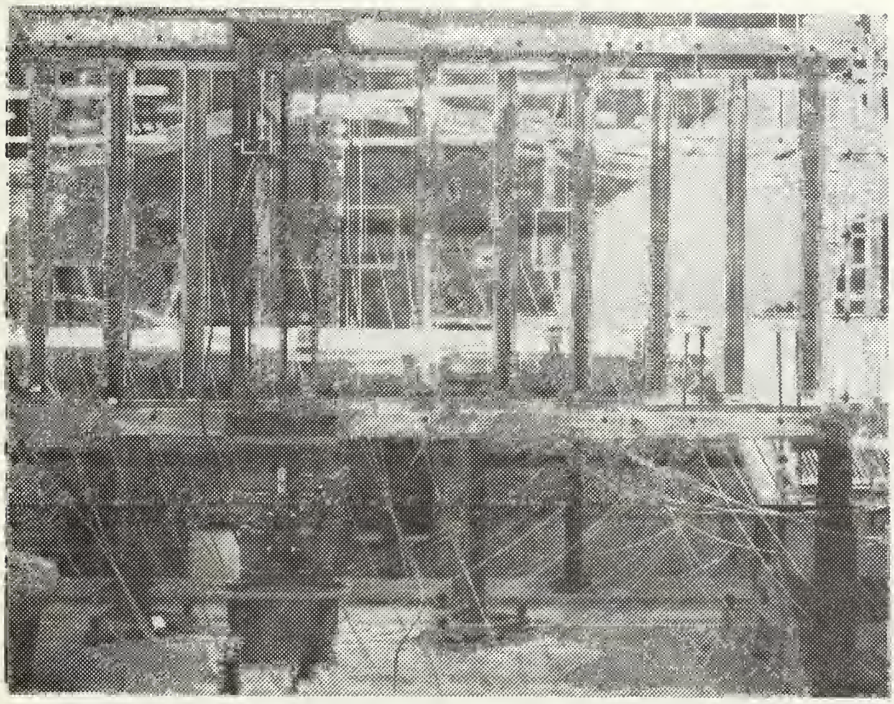


FIGURE 82

The Wind Tunnel Test Section

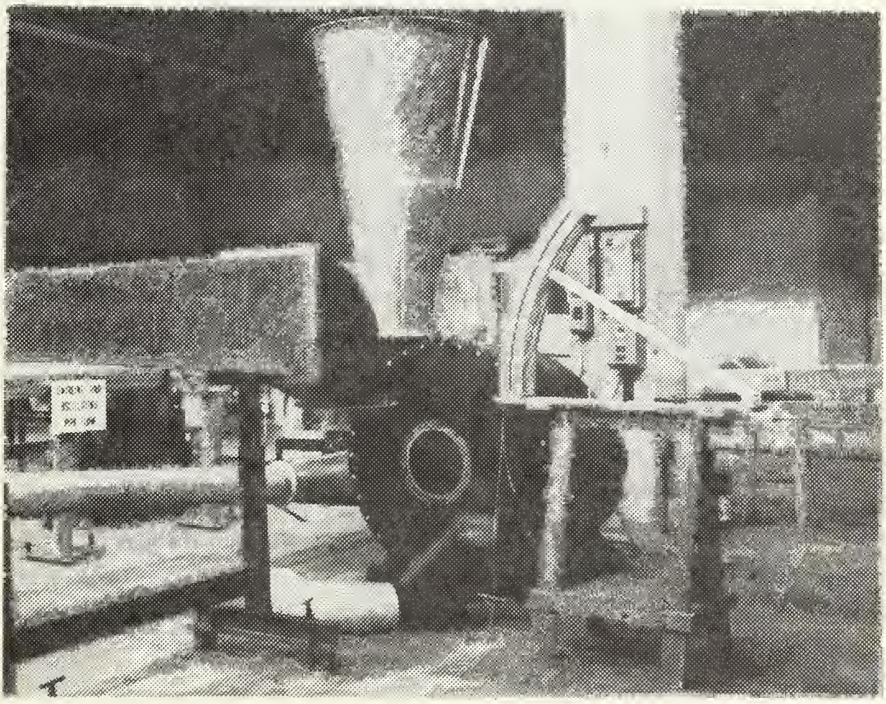


FIGURE 83

The Wind Tunnel Blower

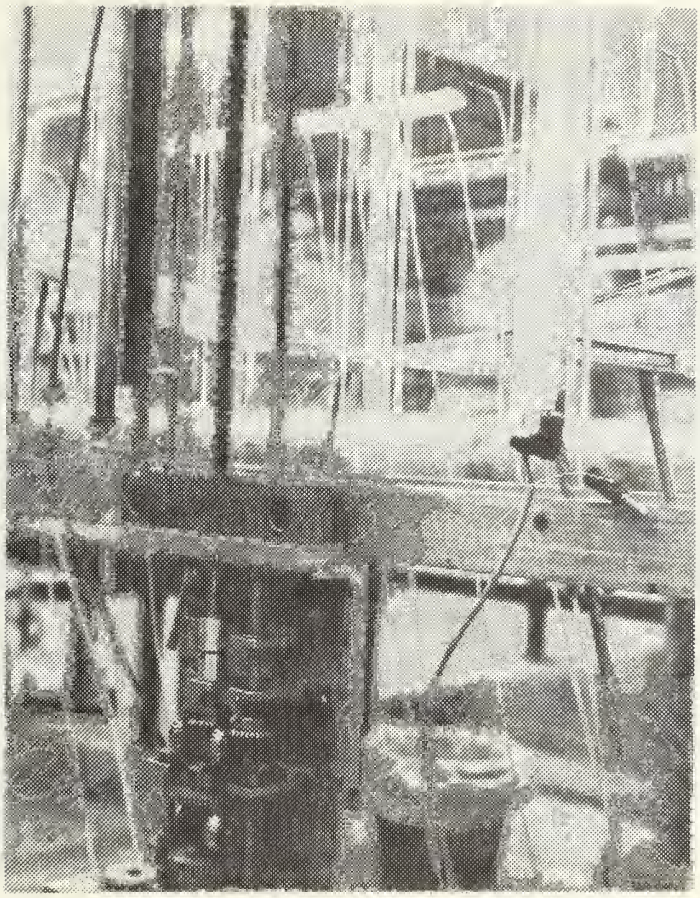


FIGURE 84

The Test Section Traverse

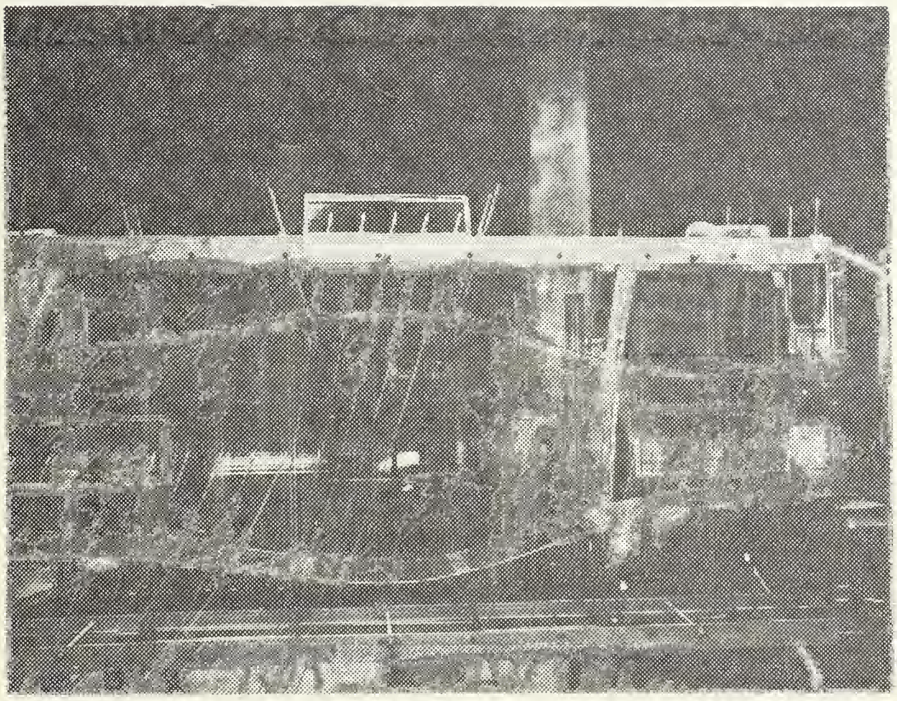


FIGURE 85

The Test Section Access Panels and Static Pressure Ports

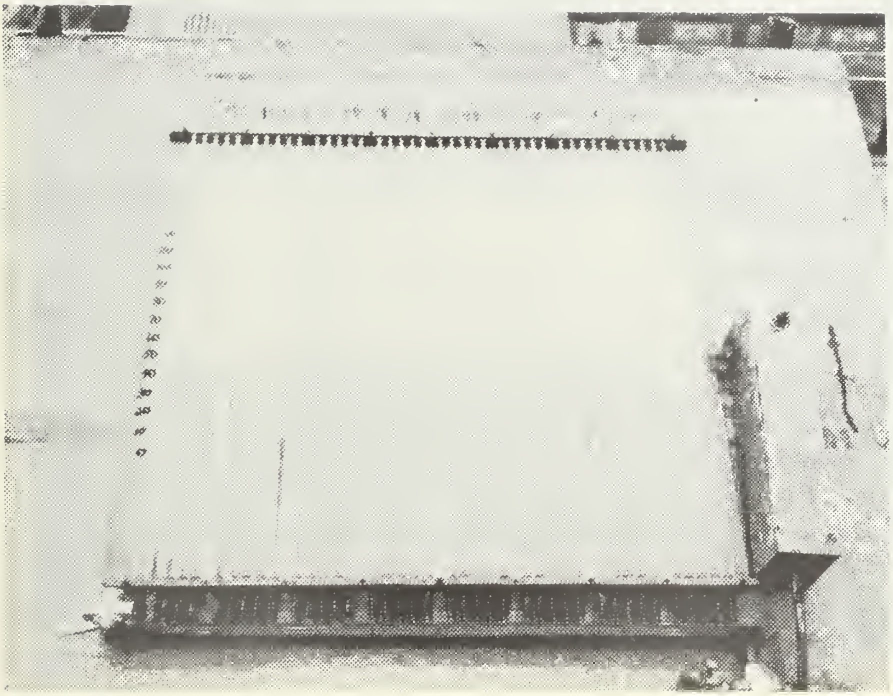


FIGURE 86

The Manometer Board

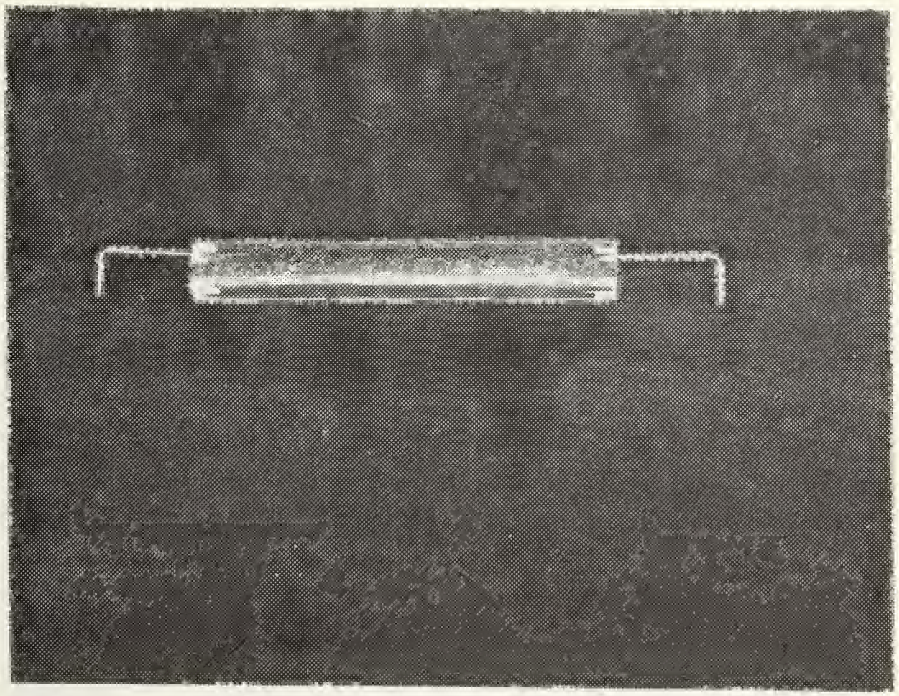


FIGURE 87

The Wake Generator

with Abrasive Strip

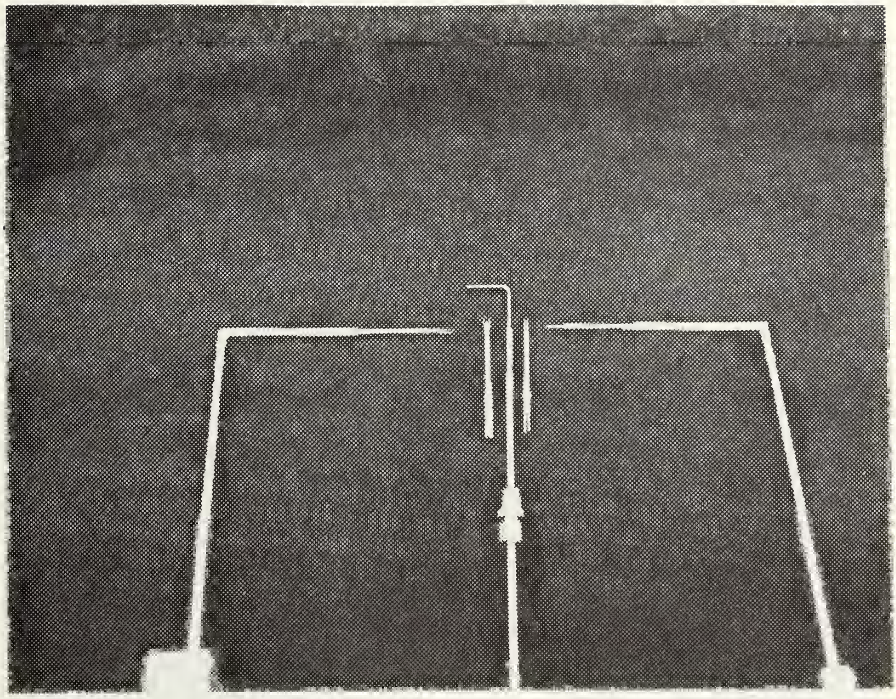


FIGURE 88

The Data Sensors

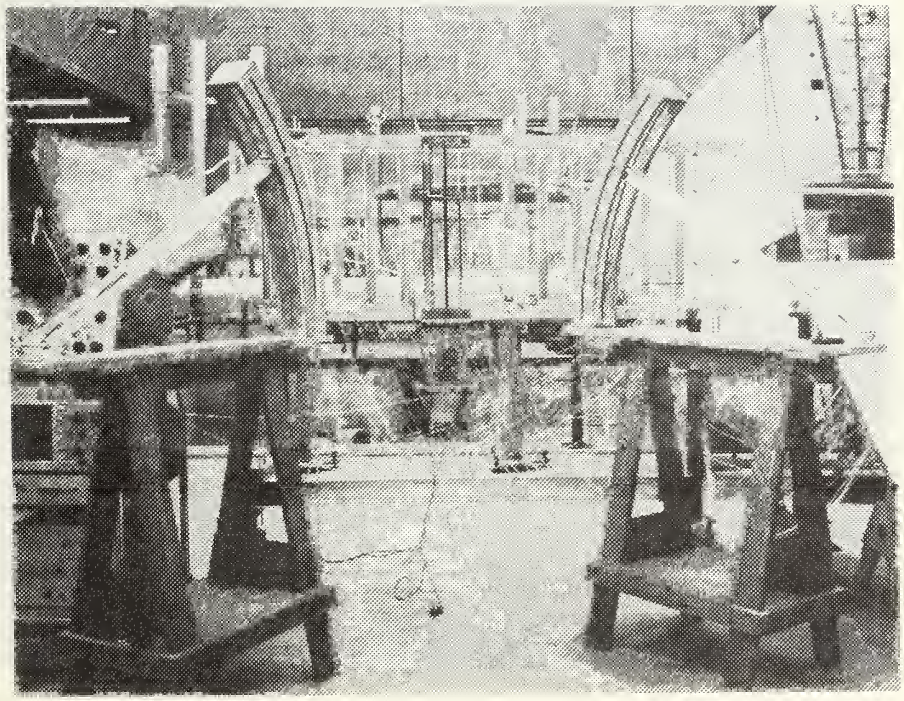


FIGURE 89

The Test Section During Phase I

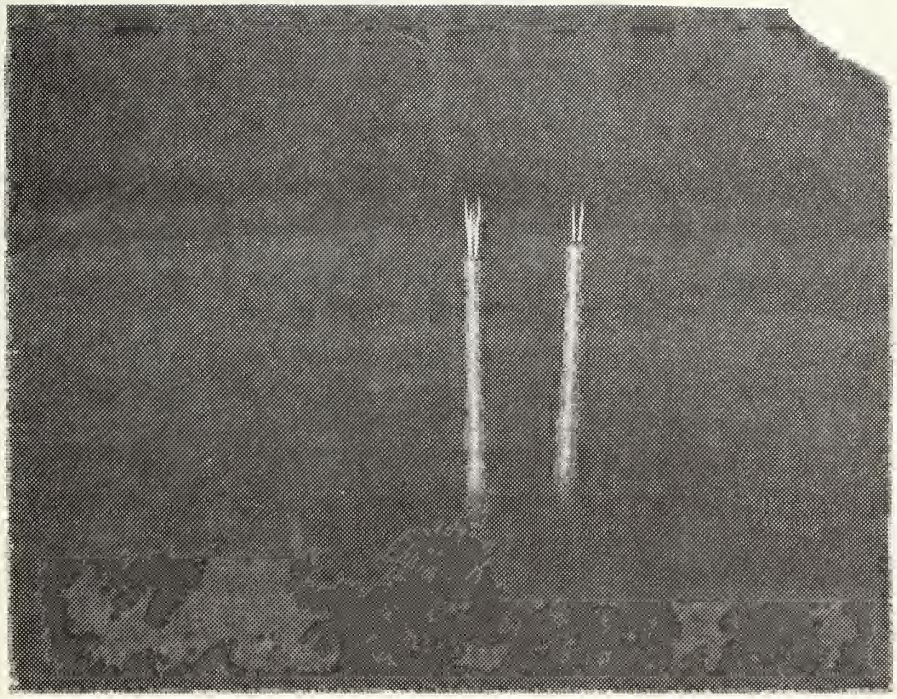


FIGURE 90

X-Array and Normal Wire
Anemometers

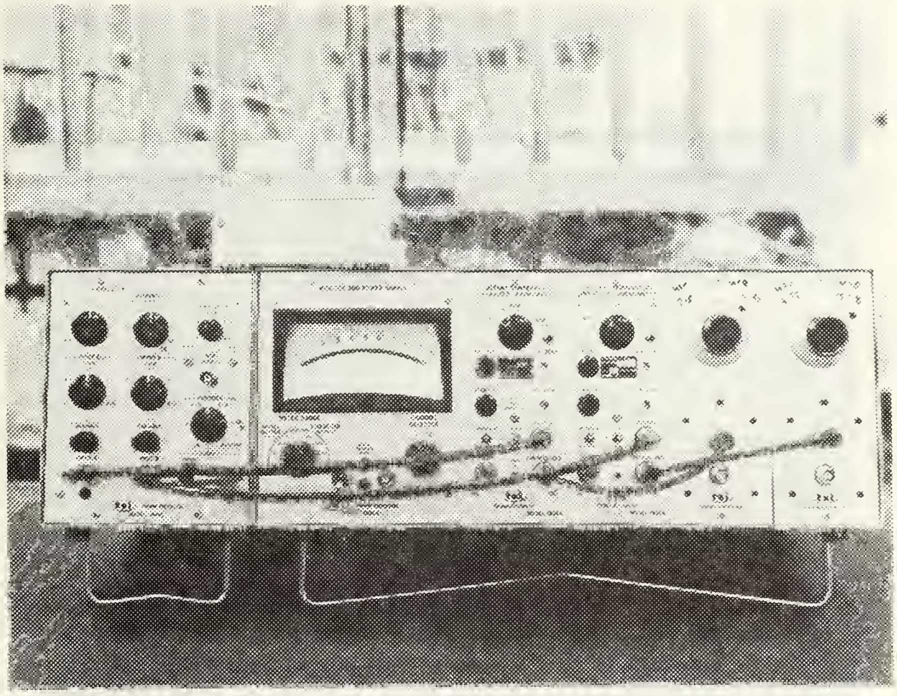


FIGURE 91

The Anemometer Modules

and Correlator

[illegible]

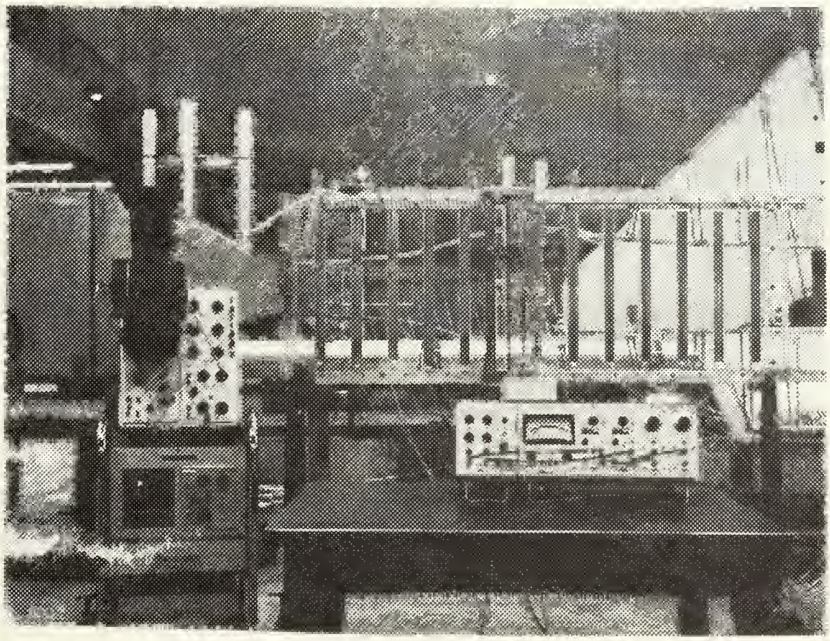


FIGURE 92

The Test Section During

Phases II and III

[illegible]

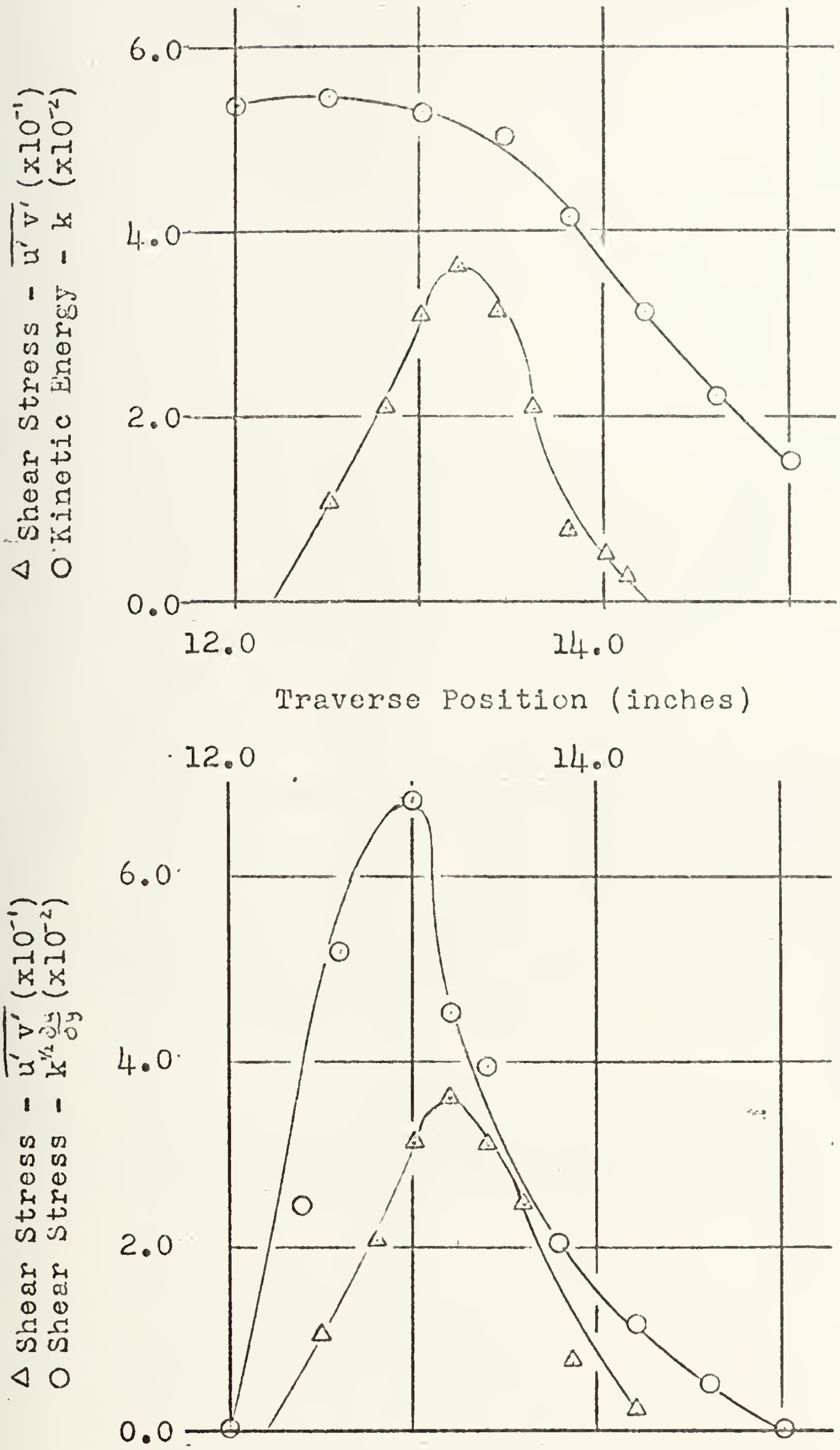


FIGURE 93

Station 2 Turbulent Stress Comparison

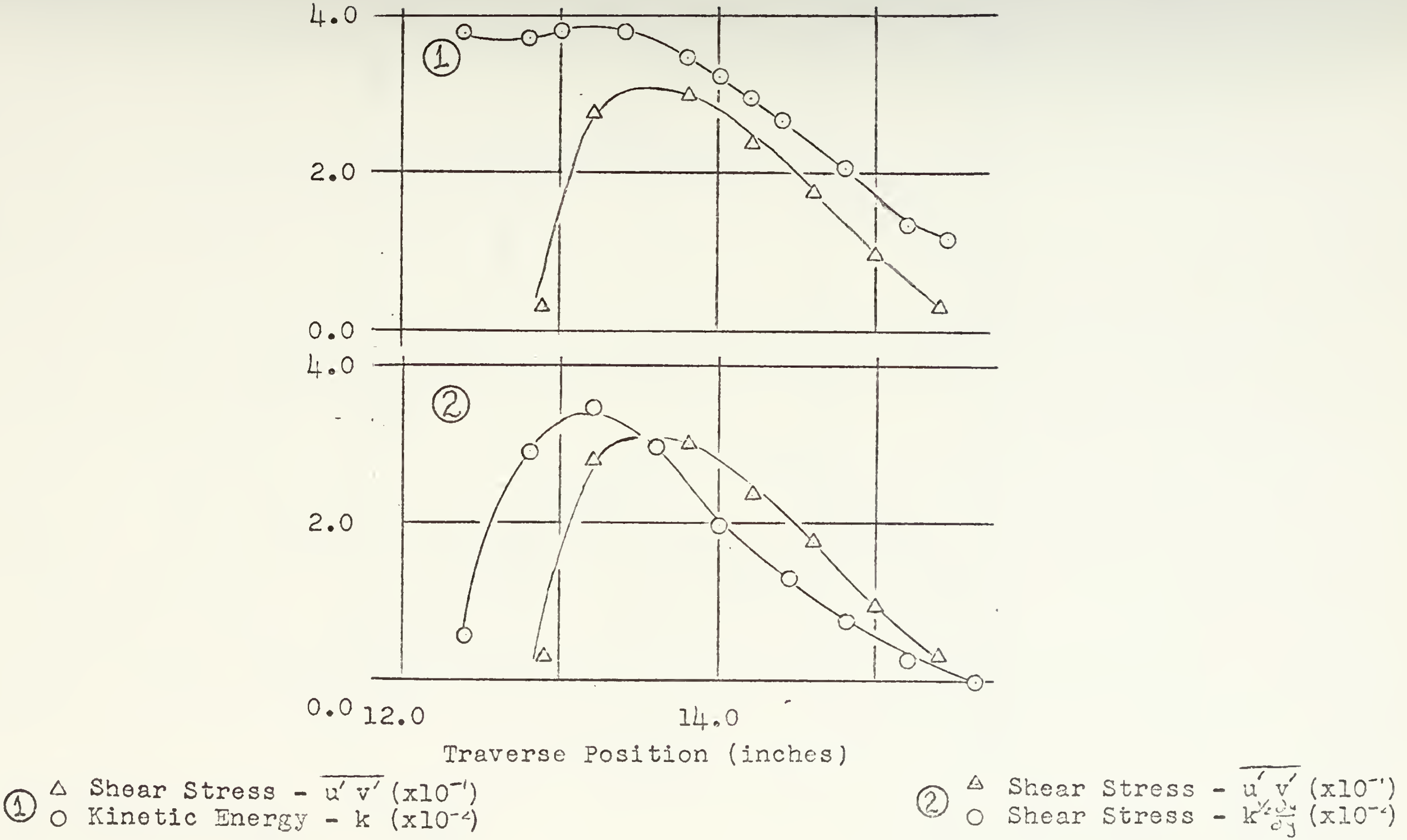


FIGURE 94
Station 3 Turbulent Stress Comparison

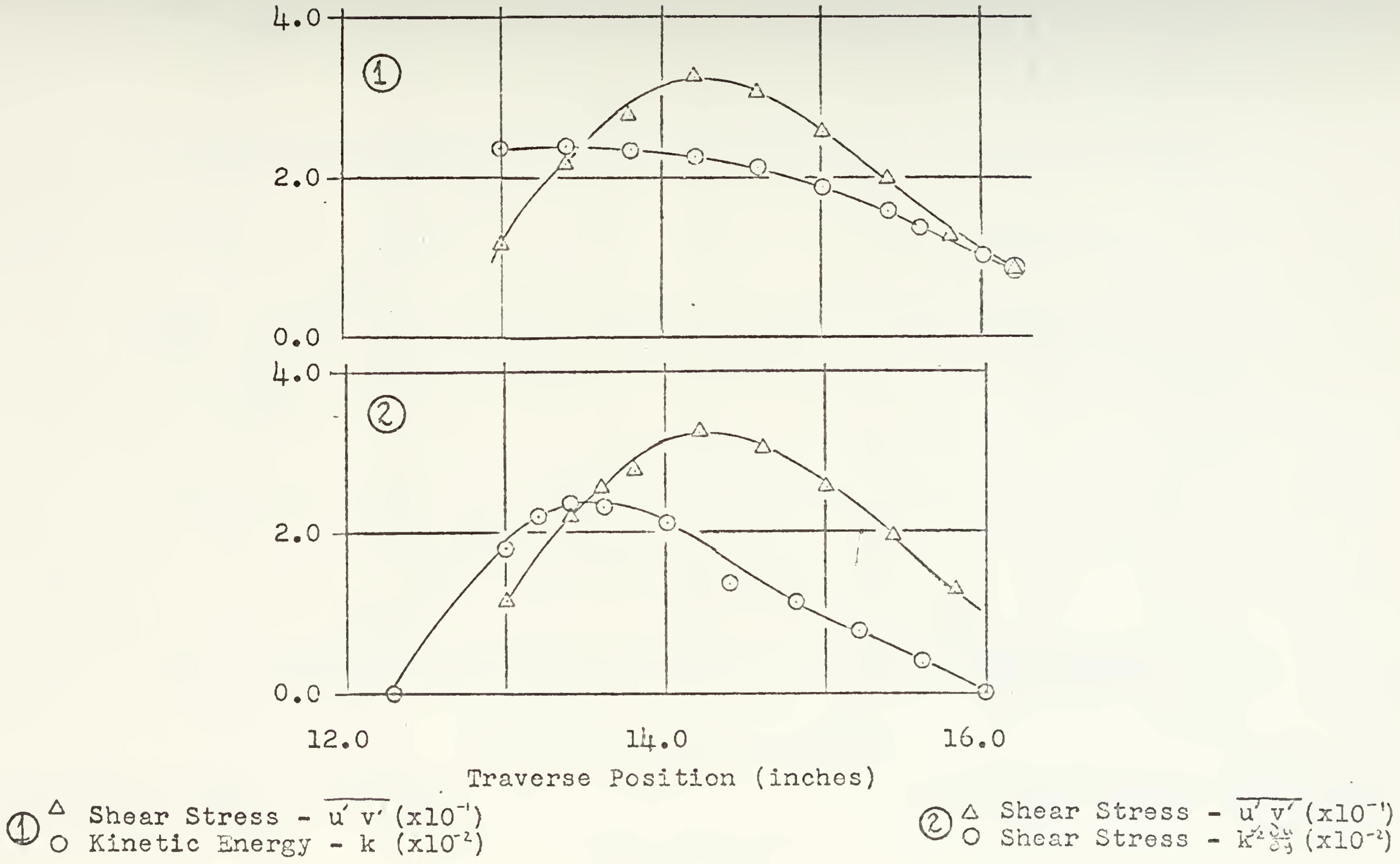


FIGURE 95
Station 4 Turbulent Stress Comparison

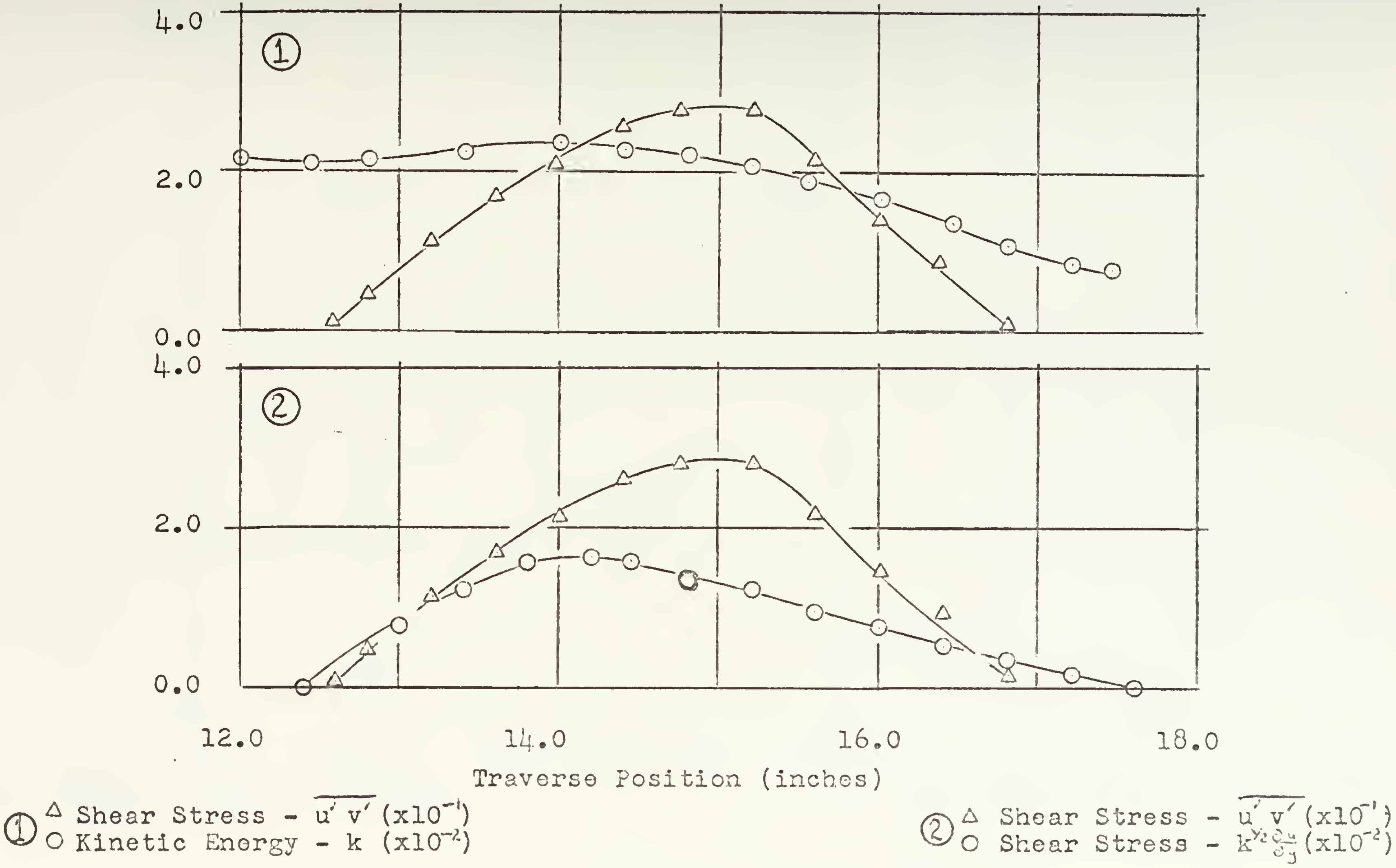


FIGURE 96
Station 5 Turbulent Stress Comparison

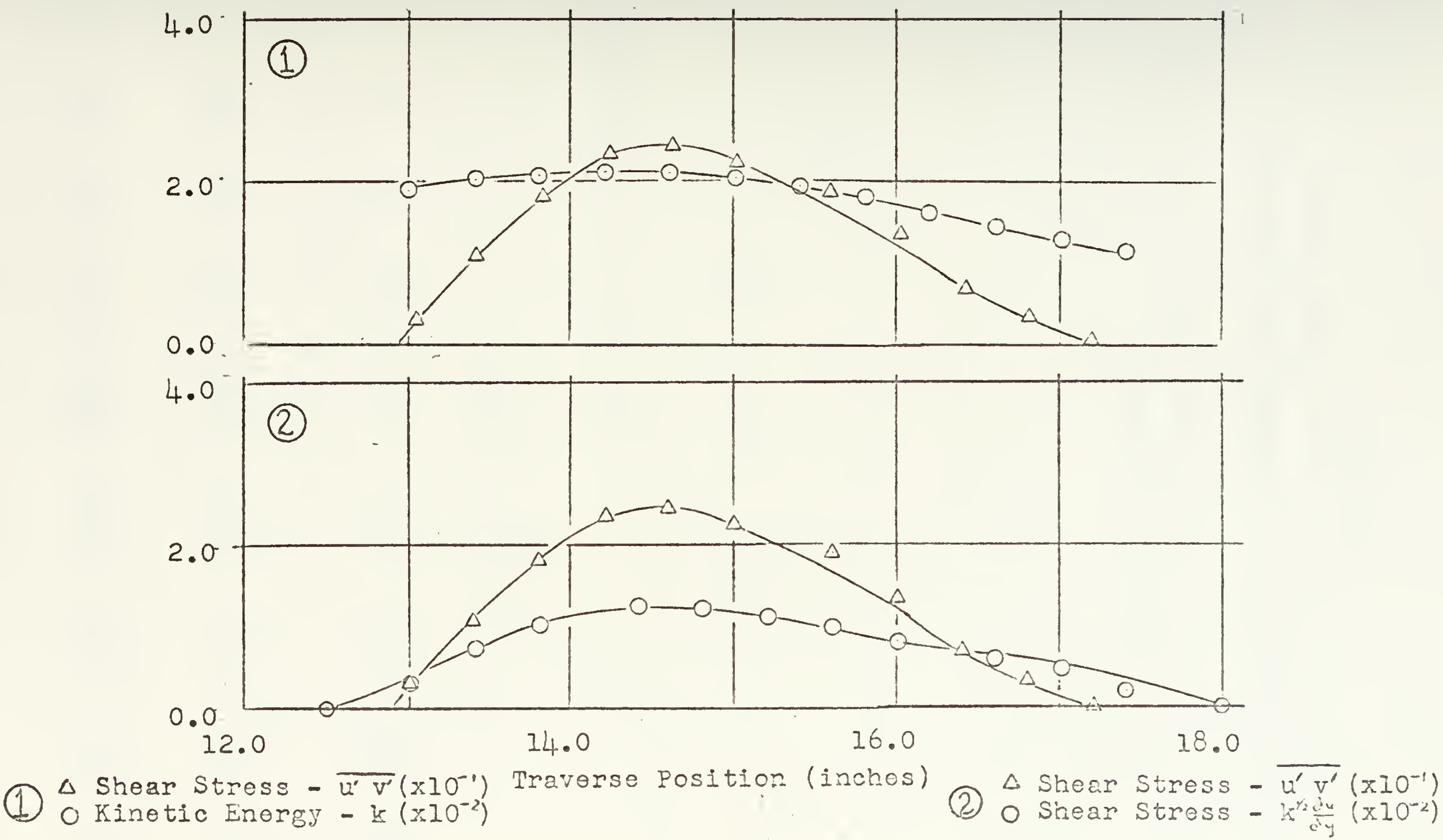


FIGURE 97
Station 6 Turbulent Stress Comparison

APPENDIX A

DEVELOPMENT OF THE GOVERNING EQUATIONS OF MOTION FOR TURBULENT INCOMPRESSIBLE FLOW

First, the following equations are the basic Navier-Stokes equation for incompressible Newtonian flow:

continuity:

$$\nabla \cdot \overline{V} = 0 \tag{A-1}$$

momentum:

$$\frac{\partial \overline{V}}{\partial t} + \overline{V} \cdot \nabla \overline{V} = -\frac{1}{\rho} \nabla P + \nu \nabla^2 \overline{V} \tag{A-2}$$

Expanding the DEL terms they are

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \tag{A-3}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + w\frac{\partial u}{\partial z} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right) \tag{A-4}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + w\frac{\partial v}{\partial z} = -\frac{1}{\rho}\frac{\partial P}{\partial y} + \nu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right) \tag{A-5}$$

$$\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial x} + v\frac{\partial w}{\partial y} + w\frac{\partial w}{\partial z} = -\frac{1}{\rho}\frac{\partial P}{\partial z} + \nu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right) \tag{A-6}$$

Now substitute equation (A-1) into (A-4), (A-5), and (A-6) to get

$$\frac{\partial u}{\partial t} + \frac{\partial}{\partial x}u^2 + \frac{\partial}{\partial y}uv + \frac{\partial}{\partial z}uw = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right)$$

$$\frac{\partial v}{\partial t} + \frac{\partial}{\partial x}uv + \frac{\partial}{\partial y}v^2 + \frac{\partial}{\partial z}vw = -\frac{1}{\rho}\frac{\partial P}{\partial y} + \nu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right)$$

$$\frac{\partial w}{\partial t} + \frac{\partial}{\partial x}uw + \frac{\partial}{\partial y}vw + \frac{\partial}{\partial z}w^2 = -\frac{1}{\rho}\frac{\partial P}{\partial z} + \nu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right)$$

With ρ and ν constant and using the following definitions

$$u = \bar{u} + u' \qquad w = \bar{w} + w'$$

$$v = \bar{v} + v' \qquad p = \bar{p} + p'$$

equation (A-3) becomes

$$\frac{\partial}{\partial x}(\bar{u} + u') + \frac{\partial}{\partial y}(\bar{v} + v') + \frac{\partial}{\partial z}(\bar{w} + w') = 0 \qquad \text{(A-7)}$$

Since the integral over time of any fluctuating quantity is zero, taking the time average of equation (A-7) results in

$$\frac{\partial \bar{u}}{\partial x} + \frac{\partial \bar{v}}{\partial y} + \frac{\partial \bar{w}}{\partial z} = 0 \qquad \text{(A-8)}$$

Then subtract this from (A-7) to get

$$\frac{\partial u'}{\partial x} + \frac{\partial v'}{\partial y} + \frac{\partial w'}{\partial z} = 0 \qquad \text{(A-9)}$$

Now substitute the definitions above into equations (A-4), then

$$\frac{\partial}{\partial t}(\bar{u}+u') + \frac{\partial}{\partial x}(\bar{u}+u')^2 + \frac{\partial}{\partial y}(\bar{u}+u')(\bar{v}+v') + \frac{\partial}{\partial z}(\bar{u}+u')(\bar{w}+w')$$

$$= -\frac{1}{\rho}\frac{\partial}{\partial x}(\bar{p}+p') + \nu\left[\frac{\partial^2}{\partial x^2}(\bar{u}+u') + \frac{\partial^2}{\partial y^2}(\bar{u}+u') + \frac{\partial^2}{\partial z^2}(\bar{u}+u')\right] \tag{A-10}$$

and after taking the time average

$$\frac{\partial \bar{u}}{\partial t} + \frac{\partial}{\partial x}\bar{u}^2 + \frac{\partial}{\partial x}\overline{u'^2} + \frac{\partial}{\partial y}\overline{uv} + \frac{\partial}{\partial y}\overline{u'v'} + \frac{\partial}{\partial z}\overline{uw} + \frac{\partial}{\partial z}\overline{u'w'} \tag{A-11}$$

$$= -\frac{1}{\rho}\frac{\partial \bar{P}}{\partial x} + \nu\left[\frac{\partial^2 \bar{u}}{\partial x^2} + \frac{\partial^2 \bar{u}}{\partial y^2} + \frac{\partial^2 \bar{u}}{\partial z^2}\right]$$

In a similar manner, one can get

$$\frac{\partial \bar{v}}{\partial t} + \frac{\partial}{\partial x}\overline{uv} + \frac{\partial}{\partial x}\overline{u'v'} + \frac{\partial}{\partial y}\overline{v^2} + \frac{\partial}{\partial y}\overline{v'^2} + \frac{\partial}{\partial z}\overline{vw} + \frac{\partial}{\partial z}\overline{v'w'} \tag{A-12}$$

$$= -\frac{1}{\rho}\frac{\partial P}{\partial y} + \nu\left[\frac{\partial^2 \bar{v}}{\partial x^2} + \frac{\partial^2 \bar{v}}{\partial y^2} + \frac{\partial^2 \bar{v}}{\partial z^2}\right]$$

$$\frac{\partial \bar{w}}{\partial t} + \frac{\partial}{\partial x}\overline{uw} + \frac{\partial}{\partial x}\overline{u'w'} + \frac{\partial}{\partial y}\overline{vw} + \frac{\partial}{\partial y}\overline{v'w'} + \frac{\partial}{\partial z}\overline{w^2} + \frac{\partial}{\partial z}\overline{w'^2} \tag{A-13}$$

$$= -\frac{1}{\rho}\frac{\partial \bar{P}}{\partial z} + \nu\left[\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right]$$

In the special case for a two-dimensional mean flow with a steady mean, equations (A-11) and (A-12) can be written

$$\frac{\partial \overline{u^2}}{\partial x} + \frac{\partial}{\partial y}\overline{uv} = -\frac{1}{\rho}\frac{\partial}{\partial x}(\bar{p}+\rho\overline{u'^2}) - \frac{\partial}{\partial y}(\overline{u'v'}) + \nu[\frac{\partial^2\bar{u}}{\partial x^2} + \frac{\partial^2\bar{u}}{\partial y^2}] \tag{A-14}$$

$$\frac{\partial \overline{uv}}{\partial x} + \frac{\partial}{\partial y}\overline{v^2} = -\frac{1}{\rho}\frac{\partial}{\partial y}(\bar{p}+\rho\overline{v'^2}) - \frac{\partial}{\partial x}(\overline{u'v'}) + \nu[\frac{\partial^2\bar{v}}{\partial x^2} + \frac{\partial^2\bar{v}}{\partial y^2}] \tag{A-15}$$

Then applying the standard boundary layer assumptions

$$P = P(x) \qquad \text{from} \qquad \frac{dP}{dx} = -\rho\ U_e\ \frac{dU_e}{dx} \tag{A-16}$$

and in addition make the following approximations

$$\rho\ \overline{u'^2} << \bar{P} \tag{A-17}$$

$$\nu[\frac{\partial^2\bar{u}}{\partial x^2} + \frac{\partial^2\bar{u}}{\partial y^2}] << \frac{\partial}{\partial y}\overline{u'v'} \tag{A-18}$$

When these assumptions are substituted into (A-14), the following equation results:

$$\frac{\partial \overline{u^2}}{\partial x} + \frac{\partial}{\partial y}\overline{uv} = -\frac{1}{\rho}\frac{\partial\bar{P}}{\partial x} - \frac{\partial}{\partial y}\overline{u'v'} \tag{A-19}$$

Which can be manipulated into the form in equation (A-20) using continuity

$$\bar{u}\ \frac{\partial\bar{u}}{\partial x} + \bar{v}\ \frac{\partial\bar{u}}{\partial y} = -\frac{1}{\rho}\ \frac{\partial\bar{P}}{\partial x} - \frac{\partial}{\partial y}\overline{u'v'} \tag{A-20}$$

applying the Boussinesq laminarization, the turbulent shear becomes

$$- \frac{\partial}{\partial y} \overline{u'v'} = \frac{1}{\rho} \tau_y = \frac{1}{\rho} (\mu_t(x) \frac{\partial \overline{u}}{\partial y}) \qquad \text{(A-21)}$$

then, $\tau = -\rho \, \overline{u'v'}$, is the Reynolds Stress, and $\mu_t(x)$, the Eddy Viscosity, is a function of the flow field. If (A-16) and (A-21) are substituted into (A-20) the result is

$$\overline{u} \frac{\partial \overline{u}}{\partial x} + \overline{v} \frac{\partial \overline{u}}{\partial y} = U_e \frac{dU_e}{dx} + \nu_T(x) \frac{\partial^2 \overline{u}}{\partial y^2} \qquad \text{(A-22)}$$

An alternate approach to solving these equations is possible without the boundary layer assumptions (A-16, 17, & 18). Since there are three equations, (A-8), (A-14), and (A-15) and six unknowns $\overline{u}$, $\overline{v}$, $\overline{p}$, $\overline{u'^2}$, $\overline{v'^2}$, and $\overline{u'v'}$, three additional equations are required. By subtracting the mean equations from the full equations as shown in (A-10), three additional momentum equations for the fluctuating portion of the flow result; however, several additional unknowns also appear:

$$\overline{u'^3}, \quad \overline{v'^3}, \text{ and } \overline{u'v'^2}.$$

One might also formulate additional equations for these variables, but higher order correlation unknowns would appear in them, and additional equations would be required

ad infinitum. It is customary at this point then to approximate $\overline{v'^2}$, $\overline{u'^2}$, and $\overline{u'v'}$ by some function of the mean flow and solve the system of equations.

APPENDIX B

DEVELOPMENT OF THE EQUATIONS FOR THE HOT-WIRE ANEMOMETER

I. Single Normal Hot-Wire

First assume the following definitions

$$e = \bar{e} + e'$$

$$u = \bar{u} + u'$$

Then, since the linearized output of the hot-wire is proportional to u

$$e = C\,u \tag{B-1}$$

or

$$\bar{e} + e' = C(\bar{u} + u') \tag{B-2}$$

Setting averages equal to averages, since they must be independent of the fluctuations,

$$\bar{e} = C\,\bar{u} \tag{B-3}$$

or solving for u

$$u = \frac{1}{C}\,\bar{e} = \frac{\bar{U}_e}{\bar{e}_e}\;\bar{e} \tag{B-4}$$

and

$$\frac{\overline{U}}{\overline{U}_e} = \frac{\overline{e}}{\overline{e}_e} \qquad \text{(B-5)}$$

Now setting the fluctuations equal

$$e' = C\ u' \qquad \text{(B-6)}$$

$$u' = \frac{1}{C}\ e'$$

$$\overline{u'^2} = \frac{1}{C^2}\ \overline{e'^2}$$

which from (B-4) becomes

$$\overline{u'^2} = \frac{\overline{U_e}^2}{\overline{e}_e^2}\ \overline{e'^2} \qquad \text{(B-7)}$$

or

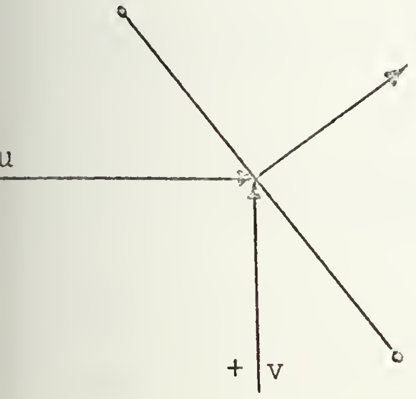
$$\frac{\overline{u'^2}}{\overline{u}_e^2} = \frac{\overline{e'^2}}{\overline{e}_e^2} \qquad \text{(B-8)}$$

II. X-array Hot-Wire

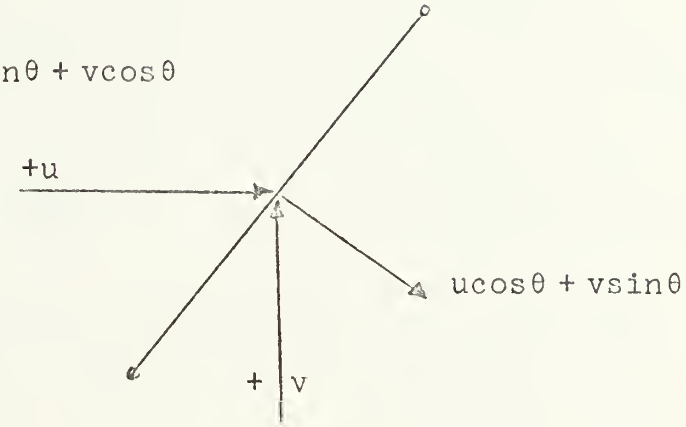
Now assume in addition, that

$$v = \overline{v} + v' \qquad e_A = \overline{e_A} + e_A' \qquad e_B = \overline{e_B} + e_B' \qquad \text{(B-9)}$$

then since the wires are separated by 90°



wire A



wire B

Now note that $\theta = 45°$ so

$$e_A = C_A (u + v)$$
$$eB = C_B (u - v) \qquad \text{(B-10)}$$

At the centerline of the flow the lateral velocity is approximately zero, so $e_A = e_B$ and, therefore, $C_A = C_B = C$. For this reason, once the probe is adjusted to force $e_A = e_B$ at the centerline the following relations hold

$$e_A = C (u + v)$$
$$e_B = C (u - v) \qquad \text{(B-11)}$$

But if these equations are summed and solved for u

$$u = \frac{1}{2C}\,[e_A + e_B] \tag{B-12}$$

and similarly

$$v = \frac{1}{2C}\,[e_A - e_B] \tag{B-13}$$

Then if $\beta \equiv 1/2\ C$, and the definitions of the parameters are substituted into (B-12) & (B-13), the resulting equations are

$$\bar{u} + u' = \beta[\overline{e_A} + e_A' + \overline{e_B} + e_B'] \tag{B-14}$$

$$\bar{v} + v' = \beta[\overline{e_A} + e_A' - \overline{e_B} - e_B'] \tag{B-15}$$

As in B-I, set averages equal to averages and

$$\bar{u} = \beta[\overline{e_A} + \overline{e_B}] = \beta[\overline{e_A + e_B}] \tag{B-16}$$

$$\bar{v} = \beta[\overline{e_A} - \overline{e_B}] = \beta[\overline{e_A - e_B}] \tag{B-17}$$

setting fluctuations equal to fluctuations,

$$u' = \beta[e_A' + e_B'] = \beta[(e_A + e_B)'] \tag{B-18}$$

$$v' = \beta[e_A' - e_B'] = \beta[(e_A - e_B)'] \tag{B-19}$$

Then square and average to get

$$\overline{u'^2} = \beta^2[\overline{(e_A + e_B)'^2}] \tag{B-20}$$

$$\overline{v'^2} = \beta^2[\overline{(e_A - e_B)'^2}] \tag{B-21}$$

Returning to equations (B-11) and setting primes equal to primes

$$\begin{aligned} e_A' &= C(u' + v') \\ e_B' &= C(u' - v') \end{aligned} \tag{B-22}$$

square and average

$$\begin{aligned} \overline{e_A'^2} &= C^2\ (\overline{u'^2} + 2\overline{u'v'} + \overline{v'^2}) \\ \overline{e_B'^2} &= C^2\ (\overline{u'^2} - 2\overline{u'v'} + \overline{v'^2}) \end{aligned} \tag{B-23}$$

then subtract

$$\overline{e_A'^2} - \overline{e_B'^2} = 4C^2\overline{u'v'} \tag{B-24}$$

or

$$\overline{u'v'} = \frac{1}{4C^2}\ [\overline{e_A'^2} - \overline{e_B'^2}] \tag{B-25}$$

Now add equations (B-23)

and

$$\overline{e_A'^2} + \overline{e_B'^2} = 2C^2[\overline{u'^2} + \overline{v'^2}]$$

or

$$\overline{u'^2} + \overline{v'^2} = 2\beta^2[\overline{e_A'^2} + \overline{e_B'^2}] \qquad \text{(B-23)}$$

Then sum (B-20) and (B-21)

$$\overline{u'^2} + \overline{v'^2} = \beta^2[\overline{(e_A + e_B)'^2} + \overline{(e_A - e_B)'^2}] \qquad \text{(B-24)}$$

equating (B-23) and (B-24), and rearranging

$$\frac{2[\overline{e_A'^2} + \overline{e_B'^2}]}{\overline{(e_A + e_B)'^2} + \overline{(e_A - e_B)'^2}} = 1 \qquad \text{(B-25)}$$

Where

$$P_{Te} - P_e = 1/2\rho[u_e^2 + v_e^2]$$

or

$$2[\frac{P_{Te} - P_e}{\rho}] = (\frac{1}{2C})^2\ \overline{(e_A + e_B)_e^2} + (\frac{1}{2C})^2\ \overline{(e_A - e_B)_e^2}$$

so

$$\beta^2 = \frac{2(P_{Te} - P_e)}{\rho[\overline{(e_A + e_B)^2} + \overline{(e_A - e_B)^2}]_e}$$

and

$$\frac{2(P_{Te} - P_e)}{\rho}$$

is a known array of data from the pitot-static phase of the study.

APPENDIX C

DEVELOPMENT OF AN INTEGRATED FORM OF THE MOMENTUM EQUATION FOR THE CALCULATION OF THE LOCAL TURBULENT SHEAR COEFFICIENT

First, the basic equations of motion for a two-dimensional mean flow are

continuity:

$$u_x + v_y = 0 \tag{C-1}$$

momentum:

$$uu_x + vu_y = -\frac{1}{\rho} P_x + \frac{1}{\rho} \tau_y \tag{C-2}$$

then integrate equation (C-1) from zero to a point y

$$u_x = -v_y$$

$$\int_0^y u_x \, dy = -\int_0^y v_y \, dy$$

$$\int_0^y u_x \, dy = -\left[v + f(x)\right]_0^y$$

thus

$$v(y) = -\int_0^y u_x \, dy + v_{y=0}$$

But $v_{y=0}$ is zero, so

$$v(y) = -\int_0^y u_x \, dy \qquad \text{(C-3)}$$

Now simply and multiply equation (C-1) by u and add to (C-2) to get

$$2uu_x + (vu_y + uv_y) = -\frac{1}{\rho} P_x + \frac{\tau_y}{\rho} \qquad \text{(C-4)}$$

where the terms on the left can be recognized as differentials of the form

$$2uu_x = (u^2)x$$

$$vu_y + uv_y = (uv)_y$$

thus equation (C-4) becomes

$$2uu_x + (uv)_y = -\frac{1}{\rho} P_x + \frac{\tau_y}{\rho}$$

and, since v(0) = 0, when this equation is integrated from y = 0 to an arbitrary point $y = y_\tau$,

$$\int_0^y 2uu_x \, dy + \int_0^{y_\tau} (uv)_y \, dy = \int_0^{y_\tau} 2uu_x \, dy + u(y_\tau)v(y_\tau)$$

and the result, when equation (C-3) is substituted for $v(y_\tau)$, is the following relation

$$\int_0^{y_\tau} 2uu_x dy - u(y_\tau)\int_0^{y_\tau} u_x dy = -\int_0^{y_\tau} \frac{P_x}{\rho} dy + \frac{\tau(y_\tau)}{\rho}$$

Which can be rearranged into the following form,

$$\int_0^{y_\tau} u_x[2u-u(y_\tau)]dy = -\frac{1}{\rho}\int_0^{y_\tau} P_x dy + \frac{1}{\rho}\tau(y_\tau) \quad \text{(C-5)}$$

And can be solved for the coefficient of shear at y_τ

$(C_\tau \equiv \frac{2}{\rho u_e^2}\tau)$

$$C_\tau(y_\tau) = \frac{1}{\rho u_e^2}\int_0^{y_\tau} P_x dy + [\frac{2}{u_e^2}\int_0^{y_\tau} u_x[2u-u(y_\tau)]dy] \quad \text{(C-6)}$$

An alternate approach to this development would be to substitute equation (C-3) into (C-2)

$$\bar{u}\frac{\partial \bar{u}}{\partial x} - \frac{\partial u}{\partial y}\int_0^y (\frac{\partial u}{\partial x})dy = -\frac{1}{\rho}\frac{\partial \bar{P}}{\partial x} + \frac{1}{\rho}\frac{\partial \tau}{\partial y} \quad \text{(C-7)}$$

Then non-dimensionalize by division by the freestream velocity squared, and use the product rule of the calculus to get the following form of the momentum equation:

$$\frac{u}{u_e}(\frac{u}{u_e})_x + (\frac{u}{u_e})^2\frac{u_{ex}}{u_e} - (\frac{u}{u_e})_y\int_0^y (\frac{u}{u_e})_x dy - (\frac{u}{u_e})_y(\frac{u_{ex}}{u_e})\int_0^y (\frac{u}{u_e})dy$$

$$= -\frac{1}{\rho u_e^2}P_x + (\frac{C_{\tau_y}}{2}) \quad \text{(C-8)}$$

Where $C_\tau \equiv \frac{2\tau}{\rho\, u_e^2}$, and the subscripts x, and y indicate partial differentiation with respect to x, and y respectively. Now, if the condition that equation (C-8) be satisfied at every point in the flow is relaxed to allow it to be satisfied on the average between y = 0 and an arbitrary point y_τ, then (C-8) can be integrated by parts to get the following relation for C_τ

$$\frac{C_\tau(y_\tau)}{2} = \int_0^{y_\tau} \left[2\left(\frac{u}{u_e}\right) - \frac{u(y_\tau)}{u_e}\right]\left[\left(\frac{u}{u_e}\right)_x + \left(\frac{u}{u_e}\right)\left(\frac{u_{ex}}{u_e}\right)\right]dy + \int_0^{y_\tau} \frac{1}{2\rho u_e^2} P_x \, dy \qquad \text{(C-9)}$$

Now if the original definition of the shear term

$$\tau \equiv - \rho\, \overline{u'v'}$$

is substituted back into equations (C-5) and (C-9), the following relations result:

$$\overline{u'v'} = \int_0^{y_\tau} u_x[u(y_\tau) - 2u]dy - \frac{1}{\rho}\int_0^{y_\tau} P_x \, dy \qquad \text{(C-10)}$$

$$\overline{u'v'} = u_e^2 \int_0^{y_\tau} \left[\frac{u(y_\tau)}{u_e} - 2\left(\frac{u}{u_e}\right)\right]\left[\left(\frac{u}{u_e}\right)_x + \left(\frac{u}{u_e}\right)\left(\frac{u_{ex}}{u_e}\right)\right]dy + \int_0^{y_\tau} \frac{P_x}{2\rho}\, dy \qquad \text{(C-11)}$$

Finally, to check the validity of these equations, let y_τ go to infinity in the limit and assume that

$$P_x = - \rho\, u_e\, u_{e_x}$$

Then, equation (C-5) becomes

$$2 \int_0^\infty uu_x dy - u_e \int_0^\infty u_x dy - \int_0^\infty u_e\, u_{e_x} dy = 0$$

Since the shear, and therefore C_τ, is zero at ∞ and then

$$2 \int_0^\infty \left(\frac{u^2}{2}\right)_x dy - \int_0^\infty [(u_e u)_x - uu_{e_x}]dy - \int_0^\infty u_e u_{e_x} dy=0$$

or

$$\int_0^\infty [(u^2)_x - (u_e u)_x + uu_{e_x} - u_e u_x]\, dy = 0$$

thus, combining terms

$$\int_0^\infty \left[u_e^2 \frac{u}{u_e} \left(\frac{u}{u_e} - 1\right)\right]_x dy + \int_0^\infty u_e u_{e_x} \left(\frac{u}{u_e} - 1\right)dy = 0 \qquad \text{(C-12)}$$

and if the flowing parameters are defined

$$\theta \equiv \int_0^\infty \frac{u}{u_e}\left(\frac{u}{u_e} - 1\right)dy; \qquad \delta^* \equiv \int_0^\infty \left(\frac{u}{u_e} - 1\right) dy$$

then equation (C-12) may be written

$$[u_e^2 \theta]_x + u_e u_{e_x} \delta^* = 0$$

which when the first term is differentiated becomes

$$u_e^2 \frac{d\theta}{dx} + 2\, u_e\, u_{e_x}\, \theta + u_e\, u_{e_x}\, \delta^* = 0$$

or dividing by u_e^2

$$\frac{d\theta}{dx} + \frac{u_{e_x}}{u_e} [2\theta + \delta^*] = 0 \qquad \text{(C-13)}$$

which is simply the well-known momentum integral equation for a boundary layer. A similar procedure will reduce equation (C-9) to (C-13) as well.

APPENDIX D

DATA CHECKS

In an experimental study, it is very important to have some idea of the quality of the data that results from the experiment. In this Appendix, several methods of checking the accuracy of the data in this study are discussed.

CONTINUITY CHECKS

Using the continuity equation, it is apparent that, since the mass flow must be constant,

$$\int_0^{\text{wall}} u\,dy = \text{constant} \qquad \text{(D-1)}$$

Therefore, this equation was added to the program described in Appendix E. The results of this check for the pitot-static data varied as much as 30% over the entire test section, yet, if the largest and smallest value are neglected the range is narrowed to ± 10%. The author believes that much of this difference is due to the inability to position the pitot-static probe near the wall in some cases, while in others, the head of the probe could be placed adjacent to the wall surface. This problem is especially critical at Station 1 where the boundary layer is thin, and mass flow near the wall, at free stream velocity, comprises a

significant part of the total mass flow in the tunnel. See the computer output in Appendix F.

MOMENTUM CHECKS

Recall the integral momentum equation derived in Appendix C,

$$\frac{d\theta}{dx} + \frac{u_{e_x}}{u_e}[2\theta + \delta^*] = 0 \qquad \text{(C-13)}$$

which is a special case for the free stream where C is zero. Taking this equation as

$$E1 = \frac{d\theta}{dx}$$

$$E2 = \frac{1}{u_e}\frac{du_e}{dx}$$

$$E3 = 2\theta + \delta$$

then the non-dimensional residual of this equation was programmed as

$$\text{Epsilon} = (E1 + E2 * E3)/(E1 - E2 * E3) \qquad \text{(D-2)}$$

and its values are listed in the computer output.

In general, this ratio showed the data to correlate fairly well with the restrictions imposed by the momentum integral equation with an average residual of less than

25% and as little as +15% for most stations; however, Station 7 data was completely out of line with a residual greater than two. The primary reason for the failure of Station 7 to check satisfactorily was an inclusion of a significant portion of data at the upper portion of the traverse that reflected boundary layer interference. The inclusion of the resulting velocity decay in the calculation of the momentum, and displacement thicknesses created a large error in their values. This error is almost certainly the cause of slightly high values of Station 8 as well.

ENERGY CHECKS

Having calculated the local turbulent shear coefficient, it was possible to also integrate to the residual in the energy integral equation,

$$\frac{d}{dx}(u_e{}^3\delta_3) = 2 \int_0^\infty \frac{\tau}{\rho} \left(\frac{\partial u}{\partial y}\right)dy \qquad \text{(D-3)}$$

where the energy thickness δ_3 is defined as

$$\delta_3 \equiv \int_0^\infty u(u_e{}^2 - u^2)dy \qquad \text{(D-4)}$$

Therefore taking the term on the left as A, and that on the right as B, the relation was programmed and,

$$\text{ZETA} = (A - B)/(A + B) \qquad \text{(D-4)}$$

The results of this data check were inconclusive. The magnitude of one of two terms above (A and B) was so much larger than the other that the difference over the sum was due solely to an error in the programming vice an inaccuracy in the raw data.

HOT-WIRE CHECKS

In Appendix B it was shown in equation (B-25) that these terms were set equal to η, and values for η are listed in Table I. It was immediately obvious in this case that the error, although not large, was directly related to the strength of the turbulence in the flow. Thus, the magnitude of the lack of algebraic correlation in this check may have been due to an inability of the equipment to handle the rapid variations caused by severe turbulence. It is important to note here, that a change of as little as 10% in the individual values of the parameters used to calculate η would bring even the worst value of η back to within 10% of 1.0. The author felt that the data from Phase III of the experiment was well within the bounds of acceptable experimental data spread.

APPENDIX E

DATA REDUCTION COMPUTER PROGRAM

A. GENERAL

The Fortran IV computer program included in this Appendix is a revised form of that developed by the study of Reference 1. The program inputs the pitot-static data of phase I of the experiment, and a limited amount of data from phase II to calculate the wake momentum thickness, displacement thickness, energy thickness, local turbulent shear coefficient, and Eddy Viscosity.

At the inception of the present study the portion of the program dealing with the turbulent shear coefficient did not produce accurate values for C_τ. The author of Reference 1 was unable to find a reason for this error since the equations appeared correct, and there were no obvious coding errors. He postulated that the unreasonable values were a result of an inability of a forward finite difference scheme to accurately approximate the partial derivatives in equation (C-9) of Appendix C. Since this appeared to be a reasonable theory, this author attempted to obtain values for the derivatives by two additional methods:

1. A least squares polynomial approximation was fitted to the data at a given position y from the

centerline then this polynomial was differentiated.

2. A central difference scheme.

Unfortunately, these improvements resulted in no significant change in the values of τ. Thus, the values for the various derivatives were printed out in detail, and an order of magnitude analysis was carried out. At this point, it was not difficult to see that the values of the parameter U were exceptionally smooth in the x-direction, and obviously not a problem to approximate, yet the values calculated by the IBM-360 were not even similar to those calculated by hand. The author then attempted to follow the instructions programmed for the computer and quickly discovered that a subtle error was hidden in the program. Since each station had a different number of points, the index corresponding to a point y above the centerline was different at each station; therefore the arrays requiring differentiation were read into a dummy variable where J = 1 corresponded to the centerline for each station. This correction produced values for the local shear coefficient that were of the right order of magnitude, and the central difference scheme was considered to produce the best values for the derivative. Some of the hot-wire data was also analyzed using this program, but the values for C_τ were not very similar to those calculated from the pitot-static data. Since the pressure term was found to be the driving force of the equation for C_τ during the order of

magnitude analysis, the author felt that approximating the static pressure data with the data from phase one would be unlikely to produce realistic values for the parameters, and no additional attempt was made to use the IBM-360 to reduce the hot-wire data.

B. NOMENCLATURE

The following parameters and arrays were used in the program; their respective dimensions are shown in parenthesis:

ALV	array used to store interpolated values of dynamic pressures (feet)
AMIXL	local Prandtl mixing length in the wake (fee)
CTAU	local turbulent shear coefficient for each point in the wake
DELRAT	ratio of succeeding DELSTR's to that at the first data station
DELSTR	wake displacement thickness (feet)
DELX	axial distance between succeeding probe tip positions (feet)
DIAMTR	diameter of wake generator (inches)
EDDY	eddy viscosity
EPSIL	residual in momentum integral equation when experimental values for THETA and SHAPE are substituted into it
LABEL	label for subroutine DRAW
MN	number of data points laterally through the wake
MX	number of axial data positions
MY	number of points (always odd) into which the wake is divided

P	array of local static pressures for each point in the wake (psf)
PATM	atmospheric pressure (inches of mercury)
Q	freestream dynamic pressure (psf)
SHAPE	wake shape factor (DELSTR/THETA)
THETA	wake momentum thickness (feet)
THETAP	inclination of static pressure manometer (degrees)
THETAV	inclination of dynamic pressure manometer (degrees)
THRAT	ratio of succeeding THETA's to that at the first data station
TITLE1	title for subroutine DRAW
TITLE4	title for subroutine DRAW
U	array of velocities for each point in the wake (feet per second)
URATIO	ratio of local wake velocity to local freestream velocity
XIN	array of probe traverse positions through the wake (inches)
XOUT	interpolated probe traverse positions for each of the MY points in the wake (inches)
XPOS	probe tip position measured from downstream side of the wake generator (inches)
YOUT	interpolated manometer readings (for YQ and YPS) for each of the MY points through the wake (inches)
YPS	static pressure manometer slant distance height difference (inches)
YQ	dynamic pressure manometer slant distance height difference (inches)
MU(X)	kinematic viscosity
MM	index of the maximum velocity

MT	index of the maximum velocity in the upper half of the data
T	dummy array of U for differential
TRATIO	dummy array of URATIO for differential
ADP	dummy array of ALP for differential
D	dummy array of for calculations Eddy Viscosity
NUM	array of MN
MBM	array of MM
MAD	array of MID
MUT	array of MT
MID	index of centerline

C. SUBROUTINES

INTEG	uses Simpson's rule to numerically integrate the function F. It must be supplied with K points (always odd) equally spaced, DELX units apart
QTFE	SSP3 library subroutine for integration using trapazoidal rule
QSF	SSP3 library subroutine for integration using Simpson's Rule
FILL	used to fill in arrays to maximum dimension with freestream values
PREIN	determines midpoint of asignally dimensioned array
UTOP	determines MT, & MM
SPLIT	takes the entire array and puts the values above the centerline into a second array in the input parameters

D. USAGE

The details on the use of this program are listed in the comments at the head of the program. The deck requires 120K to compile and 230K to run.

APPENDIX E

DATA REDUCTION COMPUTER PROGRAM

```
C
C
C
C
C     *****************************************************
C
C      A HOT-WIRE ANEMOMETER STUDY OF FREE TURBULENT MIXING
C      IN AXIAL PRESSURE GRADIENTS.
C
C      ****************************************************
C
C        THIS PROGRAM WAS DESIGNED TO REDUCE PITOT-STATIC,
C     AND HOT-WIRE ANEMOMETER DATA TO DETAILED DATA
C     CONCERNING THE PHYSICAL PAPAMETERS OF THE AIR FLOW.
C     IT WAS SPECIFICALLY DESIGNED FOR USE IN THE THESIS
C     PROJECT OF LT. M. E. DEARNEY IN 1972, HOWEVER, THE
C     PROGRAM WILL BE USEFUL TO ANYONE WHO HAS DATA OF A
C     SIMILAR NATURE.
C
C     TYPE OF DATA REQUIRED
C
C         EITHER PITOT STATIC, OR HOT WIRE DATA (WITH A
C     VELOCITY REF.) AT EQUAL INTERVALS ACROSS A PARALLEL
C     FLOW 2-DIMENSIONAL WIND TUNNEL.  THE PROGRAM IS
C     PRESENTLY SET UP TO ANALYZE 3 SETS OF DATA OF 12
C     STATIONS EACH, THE FIRST BEING PITOT STATIC VALUES
C     AND THE SECOND AND THIRD, HOT-WIRE DATA.  ONLY MINOR
C     MODIFICATIONS WOULD BE REQUIRED TO EXTEND THIS TO
C     MANY MORE EXPERIMENTS.
C
C          INPUT:
C
C               1. SIX TITLE DESCRIPTION CARDS
C               2. ONE LABEL, INTERGERS FROM 1-12
C               3. FIRST RUN TITLE
C               4. FIRST 2 LINES, NUMBER OF STATIONS
C                  DIAMETER OF CYCLINDER(NOT REQUIRED)
C               5. ONE OR MORE CARDS WITH MANOMETER ANGLES
C               6. ONE OR MORE CARDS WITH ATMOSPHERIC
C                  PRESSURES.
C               7. TITLE  OF FIRST STATION, FIRST RUN
C               8. FIRST 3 LINES, INTERGER NUMBER OF POINTS
C                   I<175.
C               9. REFERENCE VALUE OF FIRST POINT
C              10. DYNAMIC PRESSURES IN INCHES(PT-PS)
C              11. STATIC PRESSURES IN INCHES(PS)
C              12. SAME DATA 7-11 FOR FOLLOWING STATIONS
C              11. SECOND RUN TITLE
C              14. NUMBER OF STATIONS
C                  DIAMETER OF CYCLINDER
C              15. SAME AS 5,6, & 7
C              16. NUMBER OF POINTS
C              17. REFERENCE VALUE
C              18. VOLTAGE DATA
C              19. THEN CONTINUE FOR THE REST OF THE STATIO
C                  THE THIRD RUN IS THE SAME AS THE FIRST.
C
C          MAJOR VARIABLES
C
C               U-VELOCITY
C               CTAU-COEFFICIENT OF STRESS
C               MU(X), VISCOUSITY MODEL
C               P-PRESSURE
C               URATIO- U/U(FREE STREAM)
C               ALP- PSTATIC/12
C               ALV- PDYNAMIC/12
C               EDDY- EDDY VISCOUSITY
C               AMISL- REYNOLD'S MIXING LENGTH
C
C          MAJOR SUBROUTINES
C
C               INTEG- INTEGRATE BY SIMPSONS RULE
```

```
C                   QTFE- INTEGRATE BY TRAPAZOIDAL RULE
C                   FILL- FILL THE VELOCITY AND PRESSURE ARRAYS
C                         FOR COMPUTATIONAL PURPOSES.
C                   PREIN- DETERMINE THE MIDPOINT OF THE WAKE
C                          DEFECT.
C                   SM- USED IN CONJUNCTION WITH LEAST SQUARES
C                       ROUTINE FOR TAKING DERIVITIVES,
C                       1=U, 2=DU.
C                   SPLIT- DETERMINE THE MIDPOINT OF THE FLOW
C                   UEE- DETERMINE THE MAX FLOW VELOCITY
CC
C
C       ********************************************
C
C
      IMPLICIT REAL*4 (A-H,O-Z)
      REAL*8  TITLE1(12)
      REAL*8  TITLE2(12)
      REAL*8  TITLE4(12)
      REAL*8  LABEL1/'    DELS'/
      REAL*8  LABEL2/'    THET'/
      REAL*8  LABEL3/'    SHAP'/
      REAL*4  LABEL(12)
      DIMENSION YFAT(12),YFIT(12),YFOT(12),YFUT(12)
      DIMENSION ALP(12,175),ALV(12,175),U(12,175),P(12,175)
      DIMENSION AMU(12),MUT(12)
      DIMENSION A(12,175),B(12,175),C(12,175),D(12,175)
      DIMENSION EDDY(12,175),AMIXL(12,175),XOUT(12,175)
      DIMENSION URATIO(12,175),CTAU(12,175),YQ(175),YPS(175)
      DIMENSION UR(175),UP(175),UC(175),UD(175),F(175)
      DIMENSION YOUT(175),XIN(175)
      DIMENSION AXIS(175)
      DIMENSION DELSTR(12),THETA(12),SHAPE(12),EPSIL(12)
      DIMENSION  T(12,175),ADP(12,175)
      DIMENSION O(12),DELRAT(12),THRAT(12),THETAV(12)
      DIMENSION THETAP(12),PATM(12),XPOS(12),DELY(12)
      DIMENSION WX(12),WH(12),IW(12)
      DIMENSION XFIT(12)
      DIMENSION RAKE(175)
      DIMENSION FAKE(175),MAD(12),MBM(12)
      DIMENSION NUM(12)
      COMMON/A/ H
      DATA GAMA/62.32/,RHO/0.002378/
      H=0.1E0
      Y=H/12.0
C
C
C     SET INPUT/OUTPUT FORMATS
C
 50   FORMAT('
     1')
 51   FORMAT(I2,F10.2)
 52   FORMAT(8F10.1)
 53   FORMAT(8F10.2)
 54   FORMAT('
     1')
 55   FORMAT(I3)
 56   FORMAT(8F10.3)
 57   FORMAT(///////' ',T20,6A8)
 58   FORMAT(///////' ',T20,12A4)
 70   FORMAT(//////////' ',T33,'ECHO-CHECK DATA'///)
 71   FORMAT(//' ',T20,'THETAV',(' ',T33,8F10.2//))
 72   FORMAT(//' ',T20,'THETAP',(' ',T33,8F10.2//))
 73   FORMAT(//' ',T20,'PATM',(' ',T33,8F10.2//))
 74   FORMAT(//' ',T20,'XPOS',(' ',T33,8F10.2//))
 75   FORMAT(///' ',T53,'MN=',I3///)
 76   FORMAT(//' ',T10,'XIN',(' ',T21,8F10.3//))
 77   FORMAT(//' ',T10,'YQ ',(' ',T21,8F10.3//))
 78   FORMAT(//' ',T10,'YPS',(' ',T21,8F10.3//))
 79   FORMAT('1',T50,'***RESULTS OF DATA REDUCTION***')
 80   FORMAT('1'//////' ',T50,'AXIAL STATION',I2,'OUT OF',I2
     1'STATIONS'/////)
```

```
FORMAT(' ',T18,'DELSTAR=',G12.5,5X,'THETA=',G12.5,5X,
1 SHAPE=',G12.5,5X,'EPSILON=',G12.5)
FORMAT(//////' ',T8,'POINT',T30,'U',T48,'U/UE',T70,'P'
1,T88,'CTAU')
FORMAT('0',T9,I3,T24,G12.5,T44,G12.5,T64,G12.5,T84,
G12.5)
FORMAT('1',T44,'***SUMMARY OF INTEGRATED WAKE PROPER',
TIES***')
FORMAT(/////' ',T3,'AXIAL',T75,'THETA'/' ',T2,'STATION
 ,T16,'X/D',T29,'DELSTAR',T44,'DELRATIO',T60,'THETA',
T75,'RATIO',T90,'SHAPE',T105,'EPSILON')
FORMAT('0',T4,I3,T11,G12.5,T26,G12.5,T41,G12.5,T56,
G12.5,T71,G12.5,T86,G12.5,T102,G12.5)
FORMAT('1',T49,'***REYNOLD"S MIXING LENGTH DATA***')
FORMAT(//////' ',T61,'STATION',I3///' ',T44,'POINT',
T59,'EDDY VISCOSITY',T79,'MIXING LENGTH')
FORMAT(' ',T45,I3,T60,G12.5,T80,G12.5)
FORMAT(6A8)
FORMAT(//' ','LAST=',I3)
FORMAT(12A4)
FORMAT(' ',T45,'MASS FLOW =',F13.5/)
FORMAT('1'//////' ',T8,'POINT',T30,'U',T48,'U/UE',T70,
,T88,'CTAU')
5FORMAT('1'//)
FORMAT('0',T60,'TURBULENCE CHECKS'///T10,'STATION',
15X,'ETA',12X,'MU(X)'//)
7FORMAT(' ',T14,I2,11X,F12.4,5X,F12.4/)


 READ(5,90)  TITLE1
 READ(5,90)  TITLE2
 READ(5,90)  TITLE4
 READ(5,92)  LABEL

 ZERO ALL ARRAYS BEFORE COMPUTATION BEGINS

 THIS LOOP CARRIES THE PROGRAM THRU THREE SETS OF DATA

                              ******************************


 DO 1000 KK=1,3
 Z=0.0
 DO 1 I=1,12
 DELRAT(I)=Z
 DELSTR(I)=Z
 DELY(I)=Z
 EPSIL(I)=Z
 PATM(I)=Z
 Q(I)=Z
 SHAPE(I)=Z
 THETA(I)=Z
 THETAP(I)=Z
 THETAV(I)=Z
 THRAT(I)=Z
 AMU(I)=Z
 XPOS(I)=Z
 DO 1 J=1,175
 A(I,J)=Z
 B(I,J)=Z
 C(I,J)=Z
 CTAU(I,J)=Z
 D(I,J)=Z
 F(J)=Z
 P(I,J)=Z
 URATIO(I,J)=Z
 XOUT(I,J)=Z
 GO TO (36,1,1), KK
3 ALP(I,J)=Z
 ALV(I,J)=Z
 U(I,J)=Z
 CONTINUE
```

```
      J7=MZ
      MZ=MZ+1
      DO 864 J=MU,175
      YPS(J)=ALP(I,ME)*12.
      YPS(J7)=YPS(MZ)
      IF(J7.EQ.1) GO TO 862
      J7=J7-1
  864 CONTINUE
  862 CONTINUE
      GO TO 43
   41 READ(5,56)   (YPS(J),J=1,MN)
C
C     ECHO-CHECK INPUT
C
   43 WRITE(6,95)
      WRITE(6,54)
      WRITE(6,75)   MN
      WRITE(6,76)   (XIN(J),J=1,MN)
      WRITE(6,95)
      WRITE(6,77)   (YQ(J),J=1,MN)
      WRITE(6,95)
      WRITE(6,78)   (YPS(J),J=1,MN)
      MY=MN
      NUM(I)=MN
C
C     CALCULATE   U VELOCITY
C
      IF(KK.GT.1) GO TO 37
      DO 3 J=1,MN
      YOUT(J)=YQ(J)
      ALV(I,J)=YOUT(J)/12.0
      U(I,J)=SQRT(2.0*GAMA*SIN(THETAV(I))*ALV(I,J)/RHO)
 3    CONTINUE
      GO TO 38
   37 MM=MBM(I)
      UDUM=U(I,MM)
      CALL PREIN(YQ,MN,MID)
      MM=MID
      DO 632 J=1,MY
  632 U(I,J)=YQ(J)
      UTOP=UEE( U,MN,UMAX,MM,I,MT)
      MV=MBM(I)
      ADUM=ALV(I,MV)
      DO 39 J=1,MY
      ALV(I,J)=(      ADUM*YQ(J))/YQ(MM)
      U(I,J)=(UDUM*YQ(J))/YQ(MM)
   39 CONTINUE
C
C     DETERMINE MAXIMUM FREESTREAM VELOCITY
C
C
   38 CALL PREIN(YQ,MN,MID)
      MM=MID
      UTOP=UEE (U,MN,UMAX, MM,I,MT)
      Q(I)=0.5*RHO*U(I,MM)**2
      WRITE(6,55) MID
      WRITE(6,55) MM
      WRITE(6,55) MT
      WRITE(6,53) UMAX
      WRITE(6,53) UTOP
      MAD(I)=MID
      MBM(I)=MM
      MUT(I)=MT
C
C     CONTINUITY CHECK
C
      DO 99 J=1,MY
   99 F(J)=U(I,J)
      J4=2
      CALL SPLIT(F,FAKE,MT,MID,J4)
      CALL INTEG(FAKE,J4,Y,RESULT)
      WRITE(6,93) RESULT
```

```
C
C     CALCULATE DISPLACEMENT THICKNESS
C
      DO 31 J=1,MY
      URATIO(I,J)=U(I,J)/U(I,MM)
      F(J)=1.0-URATIO(I,J)
 31   CONTINUE
      J1=2
      CALL SPLIT(F,FAKE,MY,MID,J1)
      CALL QTFE(Y,FAKE,RAKE,J1)
      DELSTR(I)=RAKE(J1)
      DELRAT(I)=DELSTR(I)/DELSTR(1)
C
C     CALCULATE MOMENTUM THICKNESS
C
      DO 4 J=1,MY
      F(J)=URATIO(I,J)*(1.0-URATIO(I,J))
 4    CONTINUE
      J2=2
      CALL SPLIT(F,FAKE,MY,MID,J2)
      CALL QTFE(Y,FAKE,RAKE,J2)
      THETA(I)=RAKE(J2)
      THRAT(I)=THETA(I)/THETA(1)
C
C     CALCULATE SHAPE FACTOR IN MOMENTUM INTEGRAL
C
      SHAPE(I)=DELSTR(I)/THETA(I)
C
C     CALCULATE THE PRESSURE FIELD
C
      DO 5 J=1,MY
      IF(KK.GT.1) GO TO 40
      X=XOUT(I,J)
      YOUT(J)=YPS(J)
      ALP(I,J)=YOUT(J)/12.0
      F(J)=URATIO(I,J)
   40 P(I,J)=PATM(I)- GAMA*SIN(THETAP(I))*ALP(I,J)
C
C
 5    CONTINUE
C
C
      CALL DRAW(MN,XIN,F,0,0,LABEL,TITLE1,0,0,1,1,2,2,6, 6,1
C
C
 6    CONTINUE
C
C
C     FILL IN FUNCTION ARRAYS TO MAX DIMENSION FOR
C     CALCULATIONS
C
C
C
      CALL FILL(NUM,1,U)
      CALL FILL(NUM,1,ALP)
C
C     PREPARE DUMMY VARIABLES CENTERED ON THE FLOW
C     CENTERLINE
C
      DO 711 LTB=1,2
      IF(LTB.EQ.2) GO TO 712
      DO 451 I=1,MX
      MID=MAD(I)
      DO 451 J=MID,175
      JK=J-MID+1
      T(I,JK)=U(I,J)
      ADP(I,JK)=ALP(I,J)
  451 CONTINUE
      GO TO 714
  712 DO 713 I=1,MX
      MID=MAD(I)
      JL=MID +1
      DO 713 J=MID,100
```

```
      JK=J-MID+1
      JL=JL-1
      T(I,JK)=U(I,JL)
      ADP(I,JK)=ALP(I,JL)
      IF(JL.EQ.1) GO TO 714
  713 CONTINUE
  714 CONTINUE
C
C     CALCJLATE RESIDUAL IN MOMENTUM INTEGRAL EQUATION
C
      I=1
      DELX=XPOS(I+1)-XPOS(I)
      MV=MBM(I+1)
      MM=MBM(I)
      E1=(THETA(I+1)-THETA(I))/DELX
      E2=(THETA(I)*(SHAPE(I)+2.))
      E3=(U(I+1,MV)-U(I,MM))/(DELX*U(I,MM))
      EPSIL(I)=(E1+E2*E3)/(E1-E2*E3)
      DO 7 I=2,MX1
      DELX=XPOS(I+1)-XPOS(I-1)
      M1=MBM(I-1)
      M2=MBM(I)
      M3=MBM(I+1)
      MY=NUM(I)
      E1=(THETA(I+1)-THETA(I-1))/DELX
      E2=THETA(I)*(SHAPE(I)+2.0)
      E3=(U(I+1,M3)-U(I-1,M1))/(DELX*U(I,M2))
      EPSIL(I)=(E1+E2*E3)/(E1-E2*E3)
    7 CONTINUE
      I=MX
      DELX=XPOS(I)-XPOS(I-1)
      MV=MBM(I)
      MM=MBM(I-1)
      E1=(THETA(I)-THETA(I-1))/DELX
      E2=(THETA(I)*(SHAPE(I)+2.))
      E3=(U(I,MV)-U(I-1,MM))/(DELX*U(I,MV))
      EPSIL(I)=(E1+E2*E3)/(E1-E2*E3)
C
C     CALCULATE LOCAL TURBULENT SHEAR COEFFICIENT IN WAKE
C
C     STATION ONE - FORWARD DIFFERENCE
C
C
      I=1
      MM=MBM(I)
      MY=NUM(I)-MAD(I)+1
      DELX=XPOS(I+1)-XPOS(I)
      DO 576 K=1,MY
      DO 575 J=1,K
      A(I,J)=2.*T(I,J)-T(I,K)
      B(I,J)=(T(I+1,J)-T(I,J))/DELX
      C(I,J)=(ADP(I+1,J)-ADP(I,J))/(DELX*ALV(I,MM))
  575 CONTINUE
      J4=0
      DO 574 J=1,K
      J4=J4+1
  574 F(J)=A(I,J)*B(I,J)
      CALL QTFE(Y,F,RAKE,J4)
      J5=0
      DO 573 J=1,K
      J5=J5+1
  573 F(J)=C(I,J)
      CALL QTFE(Y,F,FAKE,J5)
      CTAU(I,K)=(2./U(I,MM)**2)*RAKE(J4)-FAKE(J5)
  576 CONTINUE
C
C     STATION 2 TO (MX-1) CENTRAL DIFFERENCE
C
      DO 10 I=2,MX1
      DELX=XPOS(I+1)-XPOS(I)
      MM=MBM(I)
      MY=NUM(I)-MAD(I)+1
```

```
      MID=1
      DO 10 K=MID,MY
      DO 9 J=MID,K
      MA=J-MID+1
      A(I,J)=2.*T(I,J)-T(I,K)
      B(I,J)=(T(I+1,J)-T(I-1,J))/(2.*DELX)
      C(I,J)=(ADP(I+1,J)-ADP(I-1,J))/(2.*DELX*ALV(I,MM))
    9 CONTINUE
      J4=0
      DO 701 J=MID,K
      MA=J-MID+1
      J4=J4+1
  701 F(MA)=A(I,J)*B(I,J)
      CALL QTFE(Y,F,RAKE,J4)
      J5=0
      DO 702 J=MID,K
      MA=J-MID+1
      J5=J5+1
  702 F(MA)=C(I,J)
      CALL QTFE(Y,F,FAKE,J5)
      CTAU(I,K)=(2./U(I,MM)**2)*RAKE(J4)-FAKE(J5)
   10 CONTINUE
      IF(LTB.EQ.2) GO TO 718
      DO 521 I=1,MX
      MY=NUM(I)-MAD(I)+1
      MID=MAD(I)
      DO 521 J=1,MY
      JK=J+MID-1
      D(I,JK)=CTAU(I,J)
  521 CONTINUE
      GO TO 711
  718 DO 719 I=1,MX
      MY=NUM(I)-MAD(I)+1
      DO 921 J=1,MY
  921 F(J)=CTAU(I,J)
      MY=NUM(I)
      L=MAD(I)
      DO 920 J=2,100
      L=L-1
      CTAU(I,L)=F(J)
      IF(L.EQ.1) GO TO 922
  920 CONTINUE
  922 L=MAD(I)
      DO 923 J=L,MY
  923 CTAU(I,J)=D(I,J)
  719 CONTINUE
  711 CONTINUE
      WRITE(6,79)
      DO 14 I=1,MX
      WRITE(6,80)  I,MX
      WRITE(6,81) DELSTR(I),THETA(I),SHAPE(I),EPSIL(I)
      WRITE(6,82)
      MY=NUM(I)
      DO 13 J=1,MY
      IF(J.EQ.30) WRITE(6,94)
      IF(J.EQ.60) WRITE(6,94)
      IF(J.EQ.90) WRITE(6,94)
      IF(J.EQ.120) WRITE(6,94)
      WRITE(6,83) J,U(I,J),URATIO(I,J),P(I,J),CTAU(I,J)
 13   CONTINUE
 14   CONTINUE
      WRITE(6,84)
      WRITE(6,85)
      DO 15 I=1,MX
      XD=12.0*XPOS(I)/DIAMTR
      WRITE(6,86) I,XD,DELSTR(I),DELRAT(I),THETA(I),THRAT(I)
     1,SHAPE(I),EPSIL(I)
 15   CONTINUE
C
C     CALCULATE THE TURBULENT KINETIC ENERGY RESIDUAL AND MU
C
      DO 715 I=1,MX
```

```
      MY=NUM(I)-MAD(I)+1
      MID=MAD(I)
      DO 715 J=1,MY
      JK=J+MID-1
      CTAU(I,J)=D(I,JK)
  715 CONTINUE
      DO 230 I=1,MX
      J4=0
      MID=MAD(I)
      MT=MUT(I)
      DO 231 J=MID,MT
      J4=J4+1
      MA=J-MID+1
  231 F(MA)=(U(I,MT)**2-U(I,J)**2)*U(I,J)
      CALL QTFE(Y,F,RAKE,J4)
      YFIT(I)=RAKE(J4)*RHO
  230 CONTINUE
      MT=MUT(1)
      MID=1
      J4=0
      I=1
      DELX=XPOS(I+1)-XPOS(I)
      MY=NUM(I)
      MID=MAD(I)
      DO 236 J=MID,MY
      MA=J-MID+1
      F(MA)=CTAU(I,MA)*2.*((U(I,J-1)-U(I,J+1))/(2.*Y))
  236 J4=J4+1
      CALL QTFE(Y,F,RAKE,J4)
      YFOTI   =RAKE(J4)-(YFIT(I)-YFIT(I+1))/DELX
      YFATI   =RAKE(J4)+(YFIT(I)-YFIT(I+1))/DELX
      YFOT(I)=YFOTI/YFATI
      DO 232 I=2,MX1
      MT=MUT(I)
      DELX=XPOS(I+1)-XPOS(I)
      J4=0
      MID=MAD(I)
      DO 233 J=MID,MY
      MA=J-MID+1
      F(MA)=CTAU(I,MA)*2.*((U(I,J-1)-U(I,J+1))/(2.*Y))
  233 J4=J4+1
      CALL QTFE(Y,F,RAKE,J4)
      YFOTI   =RAKE(J4)-(YFIT(I-1)-YFIT(I+1))/(2.*DELX)
      YFATI   =RAKE(J4)+(YFIT(I-1)-YFIT(I+1))/(2.*DELX)
      YFOT(I)=YFOTI/YFATI
  232 CONTINUE
      MT=MUT(MX)
      J4=0
      I=MX
      MID=MAD(I)
      DO 237 J=MID,MY
      MA=J-MID+1
      F(MA)=CTAU(I,MA)*2.*((U(I,J-1)-U(I,J+1))/(2.*Y))
  237 J4=J4+1
      CALL QTFE(Y,F,RAKE,J4)
      YFOTI   =RAKE(J4)-(YFIT(I-1)-YFIT(I))/DELX
      YFATI   =RAKE(J4)+(YFIT(I-1)-YFIT(I))/DELX
      YFOT(I)=YFOTI/YFATI
      I=1
      MT=MUT(I)
      DELX=XPOS(I+1)-XPOS(I)
      MID=MAD(I)
      J4=0
      DO 581 J=MID,MT
      MA=J-MID+1
      F(MA)=U(I,J)**2
  581 J4=J4+1
      CALL QTFE(Y,F,RAKE,J4)
      DER=(YFIT(I+1)-YFIT(I))/DELX
      AMU(I)=DER/RAKE(J4)
      DO 234 I=2,MX1
      DELX=XPOS(I+1)-XPOS(I)
```

```
      MT=MUT(I)
      MID=MAD(I)
      J4=0
      DO 235 J=MID,MT
      MA=J-MID+1
      F(MA)=U(I,J)**2
  235 J4=J4+1
      CALL QTFE(Y,F,RAKE,J4)
      DER=(YFIT(I+1)-YFIT(I-1))/(2.*DELX)
      AMU(I)=DER/RAKE(J4)
  234 CONTINUE
      WRITE(6,96)
      DO 717 I=1,MX
  717 WRITE(6,97) I,YFOT(I),AMU(I)
C
C     CALCULATE EDDY VISCOSITY AND REYNOLD'S MIXING LENGTH
C
      WRITE(6,87)
      DO 17 I=2,MX
      WRITE(6,88) I
      MIN=((NUM(I)-1)/2)+10
      MAX=NUM(I)-10
      DO 16 J=MIN,MAX
      E1=ABS(    D(I,J)*Q(I))
      E2=ABS(U(I,J+1)-U(I,J-1))
      E3=2.0*H
      EDDY(I,J)=(E1/RHO)/(E2/E3)
      AMIXL(I,J)=SQRT(E1/(RHO*(E2/E3)**2))
      WRITE(6,89)  J,EDDY(I,J),AMIXL(I,J)
 16   CONTINUE
 17   CONTINUE
C
 1000 CONTINUE
  999 STOP
      END
C
C
C
C
C
C         **************************************************
C
C
C     THIS PROGRAM WAS DESIGNED TO INTEGRATE BY THE USE OF
C     SIMPSONS RULE.
C
C         INPUT:
C
C      CALL INTEG(F,M,DELX,RESULT)
C
C          F- ARRAY OF VALUES OF THEINTEGRAND
C          M- THE MUMBER OF POINTS
C          DELX- THE STEP SIZE
C          RESULT- THE RESULT OF THE INTEGRATION
C
C
C           *************************************************
C
C


      SUBROUTINE INTEG(F,K,DELX,RESULT)
      IMPLICIT REAL*4 (A-H,O-Z)
      DIMENSION F(1)
C     INTEGRATION BY SIMPSONS RULE
      K1=K-1
      A=F(1)+F(K)
      B=0.0
      DO 1 I=2,K1,2
      SUM=4.0*F(I)
      B=B+SUM
    1 CONTINUE
```

```
      C=0.0
      DO 2 I=3,K,2
      SUM=2.0*F(I)
      C=C+SUM
    2 CONTINUE
      RESULT=DELX*(A+B+C)/3.0
      RETURN
      END
C
C
C           **********************************************
C
C
C         THIS SUBROUTINE WAS DESIGNED TO FILL AND ARRAY WITH
C         VALUE EXISTING AT AN INDEX IN THE ARRAY.
C
C         INPUT:      CALL FILL(M,N,U)
C
C           M- AN ARRAY OF INTERGER VALUES OF THE INDEX
C           N- A FUNCTION VARIABLE
C           U- A DOUBLE DIMENSIONED ARRAY OF VALUES, U(I,J)
C              WHERE THE INDEX M IS CONTAINED IN J.
C
C
C           *********************************************
C
C
      SUBROUTINE FILL(NUM,MX,U)
      IMPLICIT REAL*4 (A-H,O-Z)
      DIMENSION NUM(1),U(12,1)
      DO 2 J=1,MX
      M=NUM(J)
      DO 1 I=M,175
    1 U(J,I)=U(J,M)
    2 CONTINUE
      RETURN
      END
C
C
C
C         ***************************  **  ****************
C
C
C
C
C         THIS SUBROUTINE WAS DESIGNED TO TAKE AN ARRAY AND
C      DETERMINE ITS MID-POINT BY MEANS OF AN ARBITRAY
C      FUNCTION, AND RETURN THE INDEX OF THAT POINT.
C
C           INPUT:
C
C                 CALL PREIN(A,N,M)
C
C                 A- THE ARRAY OF VARIABLES
C                 N- THE LIMIT OF THE VALUES TO BE CHECKED
C                 M- THE INDEX OF THE MID-POINT
C
C
C         ***********************************************
C
C
      SUBROUTINE PREIN(A,N,M)
      DIMENSION A(1)
C
C     DETERMINE MIDPOINT OF MAKE DEFECT
C
      DUM=1000.
      N1=N-2
      DO 1 I=3,N1
```

```
      B=A(I-2)+A(I-1)+A(I)+A(I+1)+A(I+2)
      C=AMIN1(B,DUM)
      IF(C.GE.DUM) GO TO 1
      DUM=B
      M=I
    1 CONTINUE
      RETURN
      END
C
C
C        ****************************************************
C
C
C       THIS SUBROUTINE WAS DESIGNED TO TAKE AN ARRAY OF
C     VALUES AND SPLIT THEM AT AN ARBITRARY POINT, AND
C     PLACE THESE VALUES IN ANOTHER ARRAY.
C
C         INPUT:
C
C                CALL SPLIT(A,B,M,N,JK)
C
C
C                  A- THE INPUT ARRAY
C                  B- THE OUTPUT ARRAY
C                  M- THE LIMIT OF THE SPLIT
C                  N- THE START OF THE SPLIT
C                  JK- THE NUMBER OF VALUES BETWEEN M, AND N
C
C
C        ****************************************************
C
C


      SUBROUTINE  SPLIT(A,B,M,N,JK)
      DIMENSION  A(1),B(1)
      IF(JK.EQ.1) GO TO 1
      DO 2 I=N,M
      B(I-N+1)=A(I)
    2 CONTINUE
      JK=M-N+1
      GO TO 5
    1 MD=M-N-1
      DO 3 I=1,MD
      IJ=N-I+1
      B(I)=A(IJ)
      IF(IJ.LE.1) GO TO 4
    3 CONTINUE
    4 JK=MD
    5 RETURN
      END
```

```
C
C
C
C        **********************************************************
C
C
C
C       THIS FUNCTION WAS DESIGNED TO SELECT THE LARGEST VAL
C     ARRAY, AND THE LARGEST VALUE IN THE TOP HALF OF THAT A
C
C
C         INPUT:
C
C
C               FUNCTION UEE(U,MY,UM,MM,I,MT)
C
C                   U- THE ARRAY TO BE SEARCHED
C                   MY- THE EXTENT OF THE ARRAY TO BE
C                      SEARCHED, AN INDEX
C                   UM- THE MAXIMUM VALUE IN THE ARRAY
C                   MM- THE INDEX OF THAT VALUE
C                   I- THE INDEX OF THE FIRST DIMENSION
C                      OF U(I,J)
C                   MT- THE INDEX OF THE LARGEST VALUE IN
C                       THE UPPER HALF OF THE ARRAY
C                   UEE- THE VALUE OF THE LARGEST VALUE IN
C                        THE TOP HALF OF THE ARRAY
C
C
C        **********************************************************
C
C


      FUNCTION UEE(U,MY,UM,MM,I,MT)
      DIMENSION U(12,1)
      UM=0.
      M=MM
      DO 1 J=1,MY
      UI=UM-U(I,J)
      IF(UI) 2,2,1
    2 UM=U(I,J)
      MM=J
    1 CONTINUE
      UEE=0.
      IF(MM.GT.M) GO TO 3
      DO 4 J=M,MY
      UI=UEE-U(I,J)
      IF(UI) 5,5,4
    5 UEE=U(I,J)
      MT=J
    4 CONTINUE
      GO TO 6
    3 UEE=UM
      MT=MM
    6 RETURN
      END
```

THE FOLLOWING IS A PRINT OUT OF THE RAW PITOT-STATIC DATA FOR THE STUDY

```
//GO.FT06F001 DD  SPACE=(CYL,(1,1))
```

```
      MM=J                                                              HOK09920
    1 CONTINUE                                                          HOK09930
      UEE=0.                                                            HOK09940
      IF(MM.GT.M) GO TO 3                                               HOK09950
      DO 4 J=M,MY                                                       HOK09960
      UI=UEE-U(I,J)                                                     HOK09970
      IF(UI) 5,5,4                                                      HOK09980
    5 UEE=U(I,J)                                                        HOK09990
      MT=J                                                              HOK10000
    4 CONTINUE                                                          HOK10010
      GO TO 6                                                           HOK10020
    3 UEE=UM                                                            HOK10030
      MT=MM                                                             HOK10040
    6 RETURN                                                            HOK10050
      END                                                               HOK10060
```

THE FOLLOWING IS A PRINT OUT OF THE RAW PITOT-STATIC DATA FOR THE STUDY

```
//GO.FT06F001 DD  SPACE=(CYL,(1,1))
//GO.SYSIN DD *
A PLOT OF THE PITOT STATIC VELOCITY
VERSUS THE TRAVERSE POSITION, FIGURE  LT KEARNEY
PLOT OF A CURVE FIT (KEARNEY,ME)

                    TITLE4

  1   2   3   4   5   6   7   8   9  10  11  12
                     HOKEI
11   1.0
   30.0        30.0        30.0        30.0        30.0        30.0        30.0        30.0
   30.0        30.0        30.0        30.0        30.0        30.0        30.0        30.0
   30.0        30.0        30.0        30.0        30.0        30.0        30.0        30.0
   30.0        30.0        30.0        30.0        30.0        30.0        30.0        30.0
   29.92       29.92       29.92       29.92       29.92       29.92       29.92       29.92
   29.92       29.92       29.92       29.92       29.92       29.92       29.92       29.92
     STATION 1  PITOT STATIC DATA
 41
    10.5
    8.46        8.45        8.41        8.39        8.36        8.27        8.24        8.11
    8.07        8.02        7.86        7.58        7.25        6.91        6.52        5.85
    5.37        4.93        4.59        4.55        4.69        5.13        5.45        5.93
    6.25        6.87        7.19        7.56        7.86        7.99        8.07        8.19
    8.28        8.31        8.48        8.46        8.47        8.49        8.48        8.48
```

```
    8.48
    8.98       9.01       9.04       9.17       9.30       9.43       9.60       9.78
   10.00      10.21      10.46      10.76      10.95      11.31      11.70      11.80
   12.02      12.15      12.18      12.14      12.10      11.96      11.81      11.53
   11.21      10.98      10.67      10.43      10.17       9.93       9.74       9.52
    9.36       9.21       9.13       8.98       8.86       8.80       8.79       8.78
    8.78
     STATION 2  PITOT STATIC DATA
  57
    9.5
    7.48       7.50       7.48       7.46       7.43       7.40       7.39       7.35
    7.31       7.21       7.15       7.07       6.99       6.92       6.78       6.65
    6.53       6.27       6.01       5.69       5.39       5.13       4.87       4.64
    4.45       4.42       4.45       4.41       4.30       4.28       4.37       4.49
    4.63       4.84       5.24       5.62       5.89       6.09       6.28       6.51
    6.66       6.84       6.87       6.96       7.03       7.11       7.17       7.28
    7.34       7.42       7.45       7.51       7.54       7.58       7.60       7.62
    7.62
    8.10       8.14       8.16       8.21       8.25       8.27       8.32       8.38
    8.46       8.49       8.54       8.58       8.64       8.69       8.74       8.78
    8.88       8.95       9.00       9.07       9.11       9.21       9.22       9.24
    9.25       9.24       9.32       9.31       9.32       9.30       9.32       9.29
    9.28       9.27       9.24       9.20       9.15       9.09       9.00       8.97
    8.89       8.79       8.73       8.67       8.62       8.56       8.50       8.47
    8.42       8.38       8.37       8.35       8.32       8.30       8.28       8.28
    8.28
     STATION 3  PITOT STATIC DATA
  66
    9.1
    7.26       7.24       7.22       7.17       7.09       7.03       6.98       6.89
    6.83       6.77       6.68       6.59       6.47       6.42       6.31       6.21
    6.12       6.02       5.87       5.71       5.57       5.42       5.24       5.04
    4.85       4.67       4.55       4.43       4.28       4.20       4.13       4.11
    4.01       3.98       3.97       4.08       4.17       4.23       4.40       4.44
    4.65       4.85       5.01       5.16       5.32       5.48       5.66       5.80
    5.92       6.07       6.15       6.27       6.34       6.42       6.50       6.59
    6.66       6.73       6.79       6.88       6.93       6.96       6.94       7.10
    7.12       7.05
    7.85       7.85       7.84       7.84       7.83       7.82       7.81       7.80
    7.80       7.81       7.81       7.81       7.81       7.83       7.84       7.85
    7.86       7.87       7.87       7.88       7.89       7.90       7.90       7.90
    7.91       7.91       7.91       7.93       7.93       7.95       7.95       7.95
    7.92       7.92       7.92       7.93       7.93       7.91       7.94       7.92
    7.92       7.92       7.92       7.91       7.92       7.90       7.89       7.89
    7.87       7.87       7.85       7.85       7.82       7.79       7.77       7.75
    7.74       7.73       7.72       7.72       7.71       7.71       7.71       7.72
    7.72       7.72
     STATION 4 PITOT STATIC DATA
```

```
75
    8.6
    5.50      5.49      5.45      5.40      5.35      5.28      5.23      5.15
    5.09      5.01      4.95      4.90      4.81      4.75      4.66      4.57
    4.49      4.38      4.29      4.18      4.09      4.01      3.92      3.79
    3.68      3.58      3.49      3.39      3.31      3.22      3.18      3.11
    3.02      2.97      2.97      2.96      2.92      2.93      2.94      2.98
    2.96      3.00      3.09      3.14      3.21      3.31      3.44      3.53
    3.62      3.82      3.92      3.98      4.05      4.16      4.28      4.35
    4.45      4.53      4.61      4.70      4.78      4.85      4.91      4.96
    5.03      5.11      5.16      5.23      5.28      5.32      5.38      5.44
    5.46      5.50      5.53
    6.27      6.27      6.27      6.27      6.27      6.27      6.27      6.27
    6.27      6.27      6.27      6.28      6.28      6.28      6.28      6.29
    6.29      6.29      6.29      6.29      6.29      6.29      6.29      6.29
    6.29      6.29      6.29      6.29      6.29      6.29      6.29      6.29
    6.29      6.29      6.29      6.29      6.29      6.29      6.29      6.29
    6.29      6.29      6.29      6.29      6.29      6.29      6.28      6.28
    6.28      6.28      6.28      6.28      6.28      6.28      6.27      6.27
    6.27      6.27      6.27      6.27      6.27      6.26      6.26      6.25
    6.25      6.25      6.25      6.25      6.24      6.24      6.24      6.24
    6.24      6.24      6.24
     STATION 5  PITOT STATIC DATA
93
    8.0
    4.15      4.12      4.08      4.06      4.04      4.00      3.97      3.92
    3.86      3.80      3.74      3.70      3.66      3.62      3.54      3.49
    3.43      3.34      3.28      3.18      3.11      3.02      2.94      2.88
    2.83      2.75      2.69      2.64      2.57      2.53      2.47      2.41
    2.36      2.32      2.27      2.21      2.17      2.14      2.13      2.11
    2.06      2.03      2.03      2.01      2.03      2.04      2.04      2.05
    2.08      2.10      2.12      2.15      2.21      2.26      2.29      2.36
    2.41      2.46      2.53      2.60      2.66      2.73      2.78      2.85
    2.90      2.98      3.07      3.14      3.20      3.25      3.31      3.38
    3.44      3.51      3.54      3.60      3.67      3.73      3.75      3.80
    3.86      3.91      3.97      4.00      4.05      4.08      4.13      4.16
    4.17      4.20      4.23      4.26      4.28
    5.05      5.05      5.05      5.05      5.06      5.06      5.06      5.06
    5.06      5.06      5.06      5.07      5.08      5.09      5.09      5.09
    5.10      5.10      5.11      5.12      5.12      5.13      5.13      5.14
    5.14      5.14      5.15      5.15      5.15      1.51      5.15      5.15
    5.15      5.15      5.15      5.15      5.15      5.15      5.15      5.15
    5.15      5.15      5.15      5.15      5.15      5.15      5.15      5.15
    5.15      5.15      5.15      5.15      5.15      5.14      5.14      5.14
    5.14      5.14      5.14      5.14      5.14      5.14      5.14      5.14
    5.14      5.14      5.14      5.14      5.14      5.14      5.13      5.13
    5.12      5.12      5.11      5.11      5.10      5.10      5.09      5.09
    5.09      5.08      5.08      5.07      5.07      5.06      5.06      5.05
```

```
    5.05      5.05      5.04      5.04      5.04
     STATION 6  PITOT STATIC DATA
111
    7.0
    3.60      3.57      3.53      3.49      3.45      3.43      3.39      3.38
    3.33      3.30      3.25      3.22      3.17      3.14      3.11      3.05
    3.02      2.97      2.92      2.86      2.82      2.77      2.73      2.69
    2.64      2.60      2.54      2.51      2.46      2.42      2.36      2.31
    2.23      2.19      2.15      2.10      2.05      1.99      1.95      1.92
    1.88      1.82      1.79      1.75      1.72      1.69      1.64      1.60
    1.59      1.56      1.56      1.56      1.56      1.56      1.56      1.56
    1.56      1.58      1.58      1.60      1.65      1.67      1.68      1.71
    1.75      1.79      1.83      1.86      1.90      1.94      2.00      2.06
    2.11      2.16      2.20      2.26      2.30      2.35      2.40      2.47
    2.52      2.57      2.64      2.71      2.77      2.82      2.87      2.91
    2.96      3.01      3.05      3.10      3.14      3.19      3.23      3.26
    3.31      3.35      3.37      3.40      3.42      3.46      3.48      3.51
    3.53      3.54      3.56      3.57      3.57      3.57      3.57
    4.46      4.46      4.46      4.46      4.46      4.47      4.48      4.49
    4.49      4.50      4.50      4.51      4.51      4.51      4.52      4.52
    4.53      4.54      4.55      4.56      4.57      4.57      4.58      4.59
    4.59      4.60      4.60      4.61      4.61      4.62      4.62      4.62
    4.62      4.62      4.62      4.62      4.62      4.62      4.62      4.62
    4.62      4.62      4.62      4.62      4.61      4.61      4.61      4.61
    4.61      4.61      4.61      4.61      4.61      4.61      4.61      4.61
    4.61      4.61      4.61      4.61      4.61      4.61      4.61      4.60
    4.60      4.60      4.60      4.60      4.60      4.60      4.60      4.59
    4.59      4.58      4.58      4.57      4.57      4.56      4.56      4.56
    4.55      4.55      4.55      4.55      4.55      4.55      4.53      4.52
    4.52      4.51      4.50      4.50      4.50      4.49      4.48      4.48
    4.48      4.47      4.46      4.46      4.45      4.44      4.43      4.41
    4.40      4.38      4.38      4.37      4.37      4.37      4.37
     STATION 7 PITOT-STATIC DATA
119
    6.7
    3.09      3.09      3.09      3.08      3.06      3.04      3.02      2.99
    2.97      2.93      2.90      2.87      2.84      2.83      2.78      2.74
    2.71      2.66      2.63      2.60      2.58      2.53      2.45      2.43
    2.37      2.34      2.29      2.25      2.21      2.18      2.13      2.07
    2.02      1.97      1.93      1.88      1.84      1.80      1.77      1.73
    1.68      1.64      1.60      1.56      1.54      1.52      1.50      1.47
    1.43      1.42      1.40      1.39      1.38      1.38      1.36      1.35
    1.37      1.38      1.37      1.39      1.40      1.40      1.41      1.42
    1.44      1.47      1.50      1.53      1.54      1.58      1.61      1.64
    1.68      1.72      1.76      1.80      1.84      1.88      1.93      1.99
    2.03      2.07      2.11      2.15      2.19      2.24      2.28      2.34
    2.39      2.43      2.47      2.51      2.54      2.57      2.61      2.66
    2.70      2.75      2.78      2.81      2.84      2.87      2.92      2.97
```

```
   2.99    3.01    3.04    3.07    3.09    3.11    3.11    3.12
   3.14    3.12    3.13    3.10    3.06    3.04    2.94
   4.07    4.08    4.09    4.10    4.10    4.11    4.12    4.13
   4.14    4.14    4.15    4.16    4.17    4.18    4.19    4.21
   4.22    4.22    4.23    4.24    4.25    4.25    4.24    4.26
   4.26    4.27    4.27    4.27    4.27    4.28    4.28    4.28
   4.28    4.28    4.28    4.28    4.29    4.29    4.29    4.29
   4.30    4.30    4.29    4.29    4.29    4.29    4.29    4.29
   4.29    4.30    4.30    4.30    4.30    4.30    4.30    4.30
   4.30    4.30    4.29    4.30    4.30    4.30    4.30    4.30
   4.30    4.29    4.29    4.29    4.29    4.30    4.30    4.30
   4.29    4.29    4.29    4.28    4.28    4.28    4.28    4.28
   4.28    4.28    4.27    4.26    4.25    4.25    4.25    4.24
   4.23    4.23    4.22    4.22    4.20    4.19    4.19    4.17
   4.17    4.15    4.15    4.15    4.14    4.13    4.13    4.12
   4.11    4.10    4.10    4.09    4.08    4.07    4.06    4.06
   4.06    4.05    4.05    4.05    4.03    4.03    3.98
    STATION 8  PITOT-STATIC DATA
107
   7.3
   3.05    3.03    3.01    2.98    2.96    2.93    2.91    2.87
   2.84    2.80    2.76    2.72    2.69    2.66    2.63    2.58
   2.55    2.51    2.46    2.42    2.40    2.37    2.33    2.28
   2.24    2.20    2.16    2.11    2.06    2.02    1.97    1.95
   1.92    1.88    1.83    1.79    1.77    1.73    1.72    1.70
   1.67    1.64    1.60    1.58    1.56    1.54    1.53    1.52
   1.52    1.52    1.52    1.52    1.52    1.53    1.54    1.55
   1.56    1.59    1.61    1.65    1.68    1.70    1.71    1.71
   1.74    1.78    1.81    1.86    1.90    1.93    1.97    2.00
   2.03    2.07    2.11    2.15    2.20    2.24    2.29    2.34
   2.39    2.42    2.45    2.49    2.53    2.57    2.62    2.66
   2.70    2.74    2.77    2.81    2.85    2.88    2.90    2.92
   2.97    3.00    3.02    3.02    3.03    3.03    3.03    3.03
   3.02    2.99    2.95    2.91
   4.27    4.27    4.28    4.28    4.29    4.30    4.30    4.30
   4.30    4.31    4.31    4.32    4.33    4.33    4.34    4.35
   4.36    4.35    4.35    4.36    4.37    4.38    4.38    4.39
   4.39    4.40    4.40    4.40    4.41    4.42    4.42    4.42
   4.42    4.42    4.42    4.42    4.43    4.42    4.43    4.43
   4.42    4.42    4.42    4.42    4.42    4.42    4.42    4.42
   4.42    4.42    4.42    4.42    4.42    4.42    4.42    4.42
   4.42    4.42    4.42    4.42    4.42    4.42    4.43    4.42
   4.41    4.41    4.42    4.42    4.42    4.42    4.41    4.40
   4.39    4.39    4.39    4.39    4.38    4.38    4.37    4.36
   4.35    4.35    4.34    4.33    4.33    4.32    4.32    4.31
   4.31    4.30    4.29    4.28    4.28    4.27    4.27    4.26
   4.26    4.25    4.24    4.23    4.22    4.20    4.19    4.19
   4.19    4.18    4.17    4.16
```

```
    STATION 9 PITOT-STATIC DATA
 87
   7.7
   3.54      3.53      3.53      3.53      3.51      3.48      3.44      3.41
   3.38      3.36      3.32      3.27      3.22      3.18      3.14      3.09
   3.05      3.00      2.95      2.90      2.85      2.80      2.77      2.72
   2.68      2.63      2.59      2.54      2.50      2.45      2.42      2.39
   2.36      2.32      2.29      2.26      2.23      2.20      2.17      2.16
   2.12      2.09      2.08      2.07      2.07      2.07      2.07      2.07
   2.08      2.08      2.08      2.09      2.13      2.16      2.18      2.20
   2.23      2.25      2.28      2.32      2.36      2.40      2.42      2.45
   2.50      2.56      2.60      2.64      2.69      2.72      2.76      2.81
   2.86      2.92      2.96      3.01      3.06      3.09      3.14      3.19
   3.24      3.27      3.32      3.37      3.39      3.42      3.46
   4.95      4.95      4.95      4.95      4.95      4.95      4.95      4.95
   4.95      4.95      4.95      4.95      4.95      4.95      4.95      4.95
   4.95      4.95      4.95      4.95      4.95      4.95      4.95      4.95
   4.95      4.95      4.95      4.95      4.95      4.95      4.95      4.95
   4.95      4.95      4.95      4.95      4.95      4.95      4.95      4.95
   4.94      4.94      4.94      4.94      4.94      4.94      4.94      4.94
   4.94      4.94      4.94      4.94      4.95      4.95      4.96      4.96
   4.96      4.96      4.96      4.96      4.96      4.96      4.96      4.96
   4.96      4.96      4.96      4.96      4.96      4.96      4.96      4.96
   4.96      4.96      4.96      4.96      4.96      4.96      4.96      4.96
   4.96      4.95      4.95      4.95      4.95      4.95      4.95
    STATION 10 PITOT-STATIC DATA
 69
   8.9
   4.61      4.59      4.57      4.55      4.50      4.46      4.42      4.37
   4.32      4.26      4.21      4.16      4.10      4.05      3.98      3.92
   3.87      3.82      3.78      3.74      3.69      3.64      3.59      3.53
   3.47      3.45      3.42      3.41      3.39      3.37      3.36      3.36
   3.36      3.36      3.35      3.36      3.36      3.36      3.36      3.37
   3.39      3.41      3.43      3.46      3.49      3.54      3.59      3.63
   3.68      3.73      3.78      3.83      3.88      3.93      3.99      4.06
   4.11      4.16      4.21      4.26      4.31      4.36      4.41      4.45
   4.49      4.54      4.56      4.58      4.60
   6.12      6.11      6.11      6.11      6.10      6.10      6.10      6.10
   6.10      6.10      6.10      6.10      6.09      6.09      6.08      6.08
   6.08      6.08      6.08      6.08      6.07      6.07      6.07      6.06
   6.06      6.07      6.07      6.07      6.08      6.08      6.08      6.08
   6.08      6.08      6.08      6.08      6.08      6.08      6.08      6.08
   6.08      6.08      6.07      6.07      6.07      6.07      6.08      6.08
   6.09      6.10      6.11      6.11      6.11      6.11      6.11      6.12
   6.12      6.12      6.12      6.12      6.13      6.14      6.15      6.16
   6.16      6.17      6.12      6.19      6.20
    STATION 11  PITOT-STATIC DATA
 63
```

```
   9.30
   5.78    5.77    5.73    5.68    5.63    5.58    5.53    5.49
   5.44    5.40    5.36    5.29    5.24    5.18    5.12    5.07
   5.03    4.99    4.95    4.92    4.89    4.86    4.83    4.80
   4.77    4.74    4.72    4.71    4.71    4.71    4.71    4.71
   4.71    4.71    4.72    4.74    4.76    4.79    4.82    4.85
   4.88    4.91    4.94    4.97    5.01    5.05    5.11    5.17
   5.23    5.28    5.33    5.39    5.43    5.47    5.51    5.55
   5.58    5.62    5.65    5.68    5.72    5.73    5.73
   7.45    7.45    7.45    7.44    7.44    7.44    7.43    7.42
   7.41    7.41    7.40    7.40    7.40    7.40    7.40    7.40
   7.40    7.40    7.40    7.40    7.40    7.40    7.40    7.40
   7.40    7.40    7.41    7.41    7.41    7.41    7.41    7.41
   7.41    7.41    7.41    7.41    7.41    7.41    7.41    7.41
   7.41    7.41    7.41    7.41    7.41    7.41    7.42    7.42
   7.43    7.44    7.44    7.45    7.45    7.45    7.46    7.46
   7.46    7.47    7.48    7.49    7.50    7.51    7.51
              HOKEI   HOT WIRE
5  1.0
  30.0    30.0    30.0    30.0    30.0    30.0    30.0    30.0
  30.0    30.0    30.0    30.0    30.0    30.0    30.0    30.0
  29.92   29.92   29.92   29.92   29.92   29.92   29.92   29.92
   STATION 2 MEAN NORMAL WIRE
71
   9.0
  10.75   10.8    10.83   10.82   10.81   10.80   10.80   10.80
  10.80   10.80   10.80   10.80   10.80   10.77   10.73   10.69
  10.63   10.59   10.50   10.47   10.35   10.23   10.10    9.95
   9.78    9.60    9.35    9.05    8.74    8.36    8.02    7.61
   7.42    7.32    7.26    7.25    7.36    7.54    7.80    8.17
   8.59    8.91    9.18    9.40    9.6     9.78   10.0    10.12
  10.24   10.32   10.40   10.5    10.57   10.61   10.65   10.69
  10.71   10.72   10.71   10.70   10.69   10.68   10.68   10.68
  10.68   10.68   10.63   10.61   10.58   10.56   10.53     .
   STATION 3 MEAN NORMAL WIRE
79
   8.5
  10.26   10.85   10.92   10.99   11.03   11.06   11.06   11.05
  11.05   11.05   11.03   11.01   10.98   10.95   10.90   10.85
  10.82   10.78   10.71   10.62   10.52   10.41   10.28   10.14
   9.99    9.80    9.62    9.44    9.20    8.93    8.64    8.30
   8.09    7.87    7.61    7.40    7.28    7.23    7.23    7.24
   7.39    7.58    7.77    8.0     8.20    8.48    8.80    9.07
   9.29    9.52    9.71    9.90   10.07   10.20   10.33   10.44
  10.51   10.59   10.66   10.72   10.79   10.84   10.90   10.93
  10.97   11.00   11.02   11.03   11.04   11.04   11.04   11.04
  11.04   11.04   11.04   11.0    10.92   10.83   10.51     .
   STATION 4 MEAN NORMAL WIRE
```

```
  85
     8.2
     9.43      10.08      10.6       10.82      10.81      10.78      10.74      10.72
    10.70      10.67      10.60      10.54      10.48      10.41      10.33      10.26
    10.17      10.06       9.95       9.84       9.73       9.60       9.48       9.36
     9.22       9.08       8.93       8.79       8.63       8.47       8.39       8.11
     7.96       7.76       7.58       7.40       7.28       7.14       7.02       6.97
     6.91       6.88       6.89       6.92       6.97       7.04       7.18       7.27
     7.47       7.70       7.90       8.08       8.27       8.42       8.58       8.71
     8.84       8.98       9.10       9.22       9.33       9.47       9.58       9.67
     9.77       9.86       9.97      10.05      10.14      10.24      10.30      10.37
    10.41      10.46      10.50      10.53      10.58      10.60      10.62      10.64
    10.67      10.68      10.69      10.60      10.00
      STATION 5 MEAN NORMAL WIRE
 107
     7.1
     4.7        6.5        7.8        8.85       9.55      10.06      10.33      10.50
    10.54      10.58      10.58      10.56      10.50      10.47      10.43      10.38
    10.34      10.28      10.22      10.20      10.11      10.00       9.93       9.82
     9.73       9.62       9.53       9.43       9.32       9.21       9.10       9.0
     8.9        8.78       8.66       8.54       8.40       8.29       8.13       7.98
     7.89       7.76       7.63       7.51       7.40       7.30       7.22       7.09
     7.00       6.89       6.77       6.67       6.58       6.54       6.49       6.47
     6.48       6.58       6.77       6.94       7.10       7.25       7.40       7.53
     7.64       7.81       7.92       8.03       8.17       8.28       8.39       8.49
     8.61       8.72       8.83       8.94       9.05       9.14       9.24       9.35
     9.46       9.55       9.63       9.72       9.82       9.91      10.0       10.1
    10.19      10.29      10.31      10.36      10.41      10.46      10.48      10.46
    10.45      10.44      10.44      10.43      10.38      10.12       9.63       8.78
     7.79       6.70       5.60
      STATION 6 HOT WIRE DATA
 149
     5.2
     1.35       1.45       1.72       1.98       2.30       2.62       3.03       3.70
     4.36       5.18       6.06       7.03       7.72       8.50       9.04       9.73
     9.95      10.16      10.16      10.16      10.18      10.18      10.17      10.16
    10.05       9.98       9.83       9.89       9.84       9.78       9.72       9.67
     9.61       9.53       9.44       9.36       9.28       9.19       9.11       9.02
     8.93       8.83       8.72       8.62       8.56       8.44       8.36       8.27
     8.15       8.05       7.93       7.85       7.75       7.64       7.50       7.38
     7.29       7.19       7.10       7.00       6.88       6.79       6.71       6.62
     6.52       6.42       6.32       6.25       6.17       6.12       6.06       6.03
     6.01       5.98       5.99       6.01       6.03       6.06       6.10       6.16
     6.20       6.27       6.35       6.44       6.57       6.63       6.70       6.79
     6.89       7.00       7.08       7.18       7.28       7.29       7.49       7.62
     7.74       7.86       7.99       8.12       8.22       8.37       8.48       8.60
     8.70       8.79       8.88       8.95       9.04       9.14       9.22       9.30
     9.37       9.44       9.51       9.58       9.66       9.71       9.78       9.84
```

```
      9.89       9.95      10.00      10.04      10.11      10.17      10.17      10.17
     10.16      10.16      10.13      10.10      10.07       9.95       9.55       9.14
      8.60       8.09       7.50       6.93       6.20       5.30       5.21       3.40
      2.81       2.30       1.82       1.52       1.42
       STATION 7 HOT WIRE DATA
 142
     4.4
      1.54       1.69       1.80       1.96       2.09       2.28       2.50       2.90
      3.26       3.61       4.00       4.48       4.87       5.38       5.80       6.39
      7.12       7.73       7.82       8.63       9.03       9.44       9.77      10.01
     10.32      10.56      10.81      11.03      11.02      11.02      11.03      10.93
     10.86      10.78      10.71      10.63      10.57      10.48      10.42      10.34
     10.24      10.17      10.09       9.99       9.91       9.80       9.71       9.61
      9.50       9.40       9.30       9.20       9.08       8.97       8.82       8.71
      8.60       8.49       8.37       8.24       8.08       7.96       7.85       7.69
      7.57       7.44       7.30       7.16       6.98       6.85       6.78       6.69
      6.50       6.40       6.37       6.31       6.26       6.23       6.21       6.18
      6.18       6.18       6.20       6.21       6.22       6.25       6.29       6.33
      6.38       6.42       6.50       6.62       6.75       6.90       7.06       7.17
      7.30       7.43       7.57       7.67       7.81       7.92       8.07       8.21
      8.34       8.48       8.62       8.72       8.84       9.00       9.11       9.22
      9.36       9.47       9.58       9.69       9.75       9.86       9.97      10.04
     10.13      10.20-     10.29      10.37      10.42      10.51      10.58      10.63
     10.73      10.76      10.82      10.87      10.92      10.97      11.00      10.98
     10.88      10.79      10.59      10.38      10.00       9.51
```

APPENDIX F

COMPUTER OUTPUT

```
                    AXIAL STATION 1OUT OF11STATIONS

              DELSTAR= 0.12447E-01      THETA= 0.10270E-01
                SHAPE=  1.2120         EPSILON= 0.56239


  YPOSITION            U             U/UE            CTAU
   10.500           135.93         0.99823       0.95899E-02
   10.600           135.85         0.99764       0.11362E-01
   10.700           135.52         0.99528       0.13215E-01
   10.800           135.36         0.99409       0.15200E-01
   10.900           135.12         0.99231       0.17109E-01
   11.000           134.39         0.98696       0.18716E-01
   11.100           134.15         0.98517       0.20302E-01
   11.200           133.08         0.97736       0.21468E-01
   11.300           132.76         0.97495       0.22836E-01
   11.400           132.34         0.97193       0.24196E-01
   11.500           131.02         0.96218       0.25231E-01
   11.600           128.66         0.94489       0.25571E-01
   11.700           125.83         0.92409       0.25282E-01
   11.800           122.84         0.90216       0.24508E-01
   11.900           119.33         0.87633       0.23064E-01
```

```
YPOSITION          U          U/UE          CTAU
  12.000        113.03      0.83009     0.20437E-01
  12.100        108.29      0.79530     0.16650E-01
  12.200        103.76      0.76203     0.11757E-01
  12.300        100.12      0.73528     0.60449E-02
  12.400        99.683      0.73207     0.0
  12.500        101.21      0.74325     0.58315E-02
  12.600        105.85      0.77733     0.10873E-01
  12.700        109.10      0.80121     0.14933E-01
  12.800        113.80      0.83574     0.17985E-01
  12.900        116.83      0.85800     0.19772E-01
  13.000        122.49      0.89955     0.20918E-01
  13.100        125.31      0.92026     0.21093E-01
  13.200        128.49      0.94364     0.20839E-01
  13.300        131.02      0.96218     0.19837E-01
  13.400        132.10      0.97011     0.18113E-01
  13.500        132.76      0.97495     0.16225E-01
  13.600        133.74      0.98217     0.14341E-01
  13.700        134.47      0.98756     0.12326E-01
  13.800        134.72      0.98934     0.10096E-01
  13.900        136.09      0.99941     0.80751E-02
  14.000        135.93      0.99823     0.53339E-02
  14.100        136.01      0.99882     0.27123E-02
  14.200        136.17       1.0000     0.20100E-03
```

```
YPOSITION          U             U/UE            CTAU
  14.300         136.09        0.99941       -0.21956E-02
  14.400         136.09        0.99941       -0.42531E-02
  14.500         136.09        0.99941       -0.60393E-02
```

```
                    AXIAL STATION 2OUT OF11STATIONS

              DELSTAR= 0.19818E-01      THETA= 0.16468E-01
                SHAPE=  1.2034          EPSILON= 0.54603

  YPOSITION          U            U/UE           CTAU
   9.5000          127.81        0.99077       0.96840E-02
   9.6000          127.98        0.99209       0.10285E-01
   9.7000          127.81        0.99077       0.10844E-01
   9.8000          127.64        0.98945       0.11506E-01
   9.9000          127.38        0.98745       0.12181E-01
   10.000          127.13        0.98546       0.13006E-01
   10.100          127.04        0.98479       0.13804E-01
   10.200          126.70        0.98212       0.14865E-01
   10.300          126.35        0.97945       0.15857E-01
   10.400          125.48        0.97272       0.16931E-01
   10.500          124.96        0.96867       0.17780E-01
   10.600          124.26        0.96323       0.18901E-01
   10.700          123.55        0.95777       0.19961E-01
   10.800          122.93        0.95296       0.21030E-01
   10.900          121.68        0.94327       0.21995E-01
```

```
YPOSITION          U            U/UE          CTAU
  11.000         120.51       0.93419       0.23070E-01
  11.100         119.42       0.92572       0.23637E-01
  11.200         117.02       0.90710       0.24177E-01
  11.300         114.57       0.88810       0.24428E-01
  11.400         111.47       0.86413       0.24557E-01
  11.500         108.50       0.84104       0.24277E-01
  11.600         105.85       0.82050       0.23468E-01
  11.700         103.13       0.79944       0.22055E-01
  11.800         100.66       0.78034       0.19893E-01
  11.900         98.582       0.76419       0.17077E-01
  12.000         98.249       0.76161       0.13569E-01
  12.100         98.582       0.76419       0.94003E-02
  12.200         98.138       0.76075       0.47806E-02
  12.300         96.906       0.75120       0.0
  12.400         96.680       0.74945       0.46651E-02
  12.500         97.692       0.75729       0.89236E-02
  12.600         99.024       0.76762       0.12665E-01
  12.700         100.56       0.77949       0.15771E-01
  12.800         102.81       0.79698       0.18208E-01
  12.900         106.97       0.82925       0.20021E-01
  13.000         110.79       0.85880       0.21100E-01
  13.100         113.42       0.87918       0.21559E-01
  13.200         115.33       0.89399       0.21446E-01
```

```
    YPOSITION            U             U/UE            CTAU
      13.300          117.11          0.90783       0.20964E-01
      13.400          119.24          0.92430       0.20379E-01
      13.500          120.60          0.93489       0.19451E-01
      13.600          122.22          0.94744       0.18488E-01
      13.700          122.49          0.94951       0.17064E-01
      13.800          123.29          0.95571       0.15750E-01
      13.900          123.91          0.96051       0.14334E-01
      14.000          124.61          0.96596       0.12956E-01
      14.100          125.13          0.97002       0.11521E-01
      14.200          126.09          0.97744       0.10379E-01
      14.300          126.61          0.98146       0.91705E-02
      14.400          127.30          0.98679       0.81833E-02
      14.500          127.55          0.98878       0.71230E-02
      14.600          128.07          0.99276       0.63287E-02
      14.700          128.32          0.99474       0.55048E-02
      14.800          128.66          0.99737       0.48320E-02
      14.900          128.83          0.99869       0.41706E-02
      15.000          129.00           1.0000       0.36122E-02
      15.100          129.00           1.0000       0.30116E-02
```

```
                    AXIAL STATION 3OUT OF11STATIONS


          DELSTAR= 0.29650E-01      THETA= 0.24545E-01
            SHAPE=  1.2080           EPSILON= 0.14891


YPOSITION          U              U/UE            CTAU
  9.1000        125.92          1.0000        0.66377
  9.2000        125.74         0.99862        0.32624E-01
  9.3000        125.57         0.99724        0.24753E-01
  9.4000        125.13         0.99378        0.16500E-01
  9.5000        124.43         0.98822        0.74171E-02
  9.6000        123.91         0.98403        0.41703E-02
  9.7000        123.47         0.98053        0.49447E-02
  9.8000        122.67         0.97418        0.56491E-02
  9.9000        122.13         0.96993        0.60965E-02
  10.000        121.59         0.96566        0.68126E-02
  10.100        120.78         0.95922        0.75033E-02
  10.200        119.97         0.95274        0.82381E-02
  10.300        118.87         0.94403        0.88959E-02
  10.400        118.41         0.94037        0.96413E-02
  10.500        117.39         0.93228        0.10381E-01
```

```
YPOSITION          U            U/UE           CTAU
  10.600        116.46        0.92486      0.11153E-01
  10.700        115.61        0.91814      0.11636E-01
  10.800        114.66        0.91060      0.12353E-01
  10.900        113.22        0.89919      0.12696E-01
  11.000        111.67        0.88685      0.13104E-01
  11.100        110.29        0.87591      0.13394E-01
  11.200        108.80        0.86403      0.13524E-01
  11.300        106.97        0.84957      0.13634E-01
  11.400        104.91        0.83320      0.13575E-01
  11.500        102.92        0.81734      0.13387E-01
  11.600        100.99        0.80203      0.13021E-01
  11.700        99.683        0.79166      0.12330E-01
  11.800        98.360        0.78115      0.11243E-01
  11.900        96.680        0.76781      0.99950E-02
  12.000        95.772        0.76060      0.82612E-02
  12.100        94.971        0.75424      0.64094E-02
  12.200        94.741        0.75241      0.43508E-02
  12.300        93.581        0.74320      0.21759E-02
  12.400        93.230        0.74041      0.0
  12.500        93.113        0.73948      0.21759E-02
  12.600        94.394        0.74966      0.43508E-02
  12.700        95.430        0.75788      0.64094E-02
  12.800        96.114        0.76331      0.82612E-02
```

```
 YPOSITION          U            U/UE            CTAU
   12.900         98.026        0.77850       0.99950E-02
   13.000         98.471        0.78203       0.11243E-01
   13.100         100.77        0.80031       0.12330E-01
   13.200         102.92        0.81734       0.13021E-01
   13.300         104.60        0.83071       0.13387E-01
   13.400         106.16        0.84306       0.13575E-01
   13.500         107.79        0.85603       0.13634E-01
   13.600         109.40        0.86880       0.13524E-01
   13.700         111.18        0.88296       0.13394E-01
   13.800         112.55        0.89381       0.13104E-01
   13.900         113.70        0.90301       0.12696E-01
   14.000         115.14        0.91438       0.12353E-01
   14.100         115.89        0.92038       0.11636E-01
   14.200         117.02        0.92932       0.11153E-01
   14.300         117.67        0.93449       0.10381E-01
   14.400         118.41        0.94037       0.96413E-02
   14.500         119.14        0.94621       0.88959E-02
   14.600         119.97        0.95274       0.82381E-02
   14.700         120.60        0.95779       0.75033E-02
   14.800         121.23        0.96281       0.68126E-02
   14.900         121.77        0.96709       0.60965E-02
   15.000         122.58        0.97348       0.56491E-02
   15.100         123.02        0.97701       0.49447E-02
```

```
YPOSITION          U            U/UE           CTAU
  15.200         123.29        0.97912       0.41703E-02
  15.300         123.11        0.97771       0.74171E-02
  15.400         124.52        0.98892       0.16500E-01
  15.500         124.70        0.99031       0.24753E-01
  15.600         124.08        0.98543       0.32624E-01
```

```
                    AXIAL STATION 4OUT OF11STATIONS


              DELSTAR= 0.40497E-01     THETA= 0.32596E-01
                SHAPE=  1.2424          EPSILON=-0.90012E-01



   YPOSITION          U              U/UE             CTAU
    8.6000          109.60          0.99728        0.28348E-01
    8.7000          109.50          0.99638        0.20850E-01
    8.8000          109.10          0.99274        0.12808E-01
    8.9000          108.60          0.98818        0.48563E-02
    9.0000          108.09          0.98359        0.14801E-02
    9.1000          107.38          0.97713        0.22065E-02
    9.2000          106.87          0.97250        0.26959E-02
    9.3000          106.05          0.96503        0.35351E-02
    9.4000          105.43          0.95939        0.38840E-02
    9.5000          104.60          0.95182        0.45416E-02
    9.6000          103.97          0.94611        0.56118E-02
    9.7000          103.45          0.94132        0.65300E-02
    9.8000          102.49          0.93263        0.72837E-02
    9.9000          101.85          0.92680        0.79054E-02
    10.000          100.88          0.91797        0.84253E-02
```

```
YPOSITION           U             U/UE            CTAU
  10.100         99.902         0.90907        0.91171E-02
  10.200         99.024         0.90107        0.97816E-02
  10.300         97.803         0.88997        0.10149E-01
  10.400         96.793         0.88078        0.10840E-01
  10.500         95.544         0.86941        0.10909E-01
  10.600         94.510         0.86000        0.11050E-01
  10.700         93.581         0.85155        0.11552E-01
  10.800         92.525         0.84194        0.12085E-01
  10.900         90.978         0.82786        0.12179E-01
  11.000         89.648         0.81576        0.11283E-01
  11.100         88.421         0.80460        0.11071E-01
  11.200         87.303         0.79442        0.10718E-01
  11.300         86.043         0.78296        0.99664E-02
  11.400         85.022         0.77366        0.92704E-02
  11.500         83.858         0.76307        0.85562E-02
  11.600         83.335         0.75832        0.76780E-02
  11.700         82.413         0.74992        0.64835E-02
  11.800         81.212         0.73899        0.53499E-02
  11.900         80.537         0.73285        0.42443E-02
  12.000         80.537         0.73285        0.29066E-02
  12.100         80.401         0.73162        0.14711E-02
  12.200         79.856         0.72666        0.0
  12.300         79.993         0.72790        0.14711E-02
```

```
   YPOSITION          U             U/UE            CTAU
    12.400          80.129         0.72914        0.29066E-02
    12.500          80.672         0.73408        0.42443E-02
    12.600          80.401         0.73162        0.53499E-02
    12.700          80.943         0.73654        0.64835E-02
    12.800          82.148         0.74751        0.76780E-02
    12.900          82.810         0.75353        0.85562E-02
    13.000          83.728         0.76189        0.92704E-02
    13.100          85.022         0.77366        0.99664E-02
    13.200          86.675         0.78871        0.10718E-01
    13.300          87.802         0.79896        0.11071E-01
    13.400          88.914         0.80908        0.11283E-01
    13.500          91.337         0.83113        0.12179E-01
    13.600          92.525         0.84194        0.12085E-01
    13.700          93.230         0.84836        0.11552E-01
    13.800          94.047         0.85579        0.11050E-01
    13.900          95.315         0.86733        0.10909E-01
    14.000          96.680         0.87975        0.10840E-01
    14.100          97.468         0.88691        0.10149E-01
    14.200          98.582         0.89705        0.97816E-02
    14.300          99.464         0.90508        0.91171E-02
    14.400          100.34         0.91304        0.84253E-02
    14.500          101.31         0.92191        0.79054E-02
    14.600          102.17         0.92972        0.72837E-02
```

```
  YPOSITION            U             U/UE            CTAU
    14.700          102.92         0.93650       0.65300E-02
    14.800          103.55         0.94228       0.56118E-02
    14.900          104.08         0.94706       0.45416E-02
    15.000          104.81         0.95372       0.38840E-02
    15.100          105.64         0.96128       0.35351E-02
    15.200          106.16         0.96597       0.26959E-02
    15.300          106.87         0.97250       0.22065E-02
    15.400          107.38         0.97713       0.14801E-02
    15.500          107.79         0.98083       0.48563E-02
    15.600          108.39         0.98634       0.12808E-01
    15.700          109.00         0.99183       0.20850E-01
    15.800          109.20         0.99365       0.28348E-01
    15.900          109.60         0.99728       0.36247E-01
    16.000          109.90          1.0000       0.44146E-01
```

```
                    AXIAL STATION 5OUT OF11STATIONS


           DELSTAR= 0.62057E-01     THETA= 0.48019E-01
             SHAPE=  1.2923          EPSILON=-0.99311E-01


  YPOSITION           U            U/UE           CTAU
    8.0000          95.201        0.98470       0.29013E-01
    8.1000          94.856        0.98113       0.21579E-01
    8.2000          94.394        0.97636       0.14685E-01
    8.3000          94.163        0.97396       0.74734E-02
    8.4000          93.931        0.97156       0.86445E-03
    8.5000          93.464        0.96674      -0.28436E-02
    8.6000          93.113        0.96310      -0.25159E-02
    8.7000          92.525        0.95702      -0.23913E-02
    8.8000          91.814        0.94967      -0.19402E-02
    8.9000          91.098        0.94226      -0.64373E-03
    9.0000          90.376        0.93479      -0.31501E-03
    9.1000          89.891        0.92978      -0.19467E-03
    9.2000          89.404        0.92474       0.22751E-03
    9.3000          88.914        0.91967       0.14039E-02
    9.4000          87.926        0.90945       0.17159E-02
```

```
  YPOSITION          U            U/UE           CTAU
    9.5000         87.303        0.90301      0.22577E-02
    9.6000         86.549        0.89521      0.26050E-02
    9.7000         85.406        0.88339      0.31841E-02
    9.8000         84.636        0.87542      0.39863E-02
    9.9000         83.335        0.86197      0.45878E-02
    10.000         82.413        0.85243      0.49874E-02
    10.100         81.212        0.84000      0.50012E-02
    10.200         80.129        0.82880      0.51411E-02
    10.300         79.307        0.82030      0.57613E-02
    10.400         78.616        0.81315      0.60524E-02
    10.500         77.497        0.80158      0.66503E-02
    10.600         76.647        0.79278      0.69061E-02
    10.700         75.931        0.78538      0.71687E-02
    10.800         74.917        0.77490      0.72238E-02
    10.900         74.332        0.76884      0.72426E-02
    11.000         73.445        0.75967      0.74339E-02
    11.100         72.548        0.75039      0.74504E-02
    11.200         71.791        0.74256      0.71090E-02
    11.300         71.180        0.73624      0.69998E-02
    11.400         70.409        0.72827      0.65547E-02
    11.500         69.472        0.71858      0.58992E-02
    11.600         68.841        0.71205      0.53576E-02
    11.700         68.363        0.70711      0.47808E-02
```

```
YPOSITION           U              U/UE           CTAU
  11.800          68.203          0.70545       0.40954E-02
  11.900          67.882          0.70213       0.32723E-02
  12.000          67.073          0.69376       0.24903E-02
  12.100          66.583          0.68869       0.17116E-02
  12.200          66.583          0.68869       0.86933E-03
  12.300          66.254          0.68529       0.0
  12.400          66.583          0.68869       0.86933E-03
  12.500          66.747          0.69039       0.17116E-02
  12.600          66.747          0.69039       0.24903E-02
  12.700          66.910          0.69208       0.32723E-02
  12.800          67.398          0.69712       0.40954E-02
  12.900          67.721          0.70047       0.47808E-02
  13.000          68.043          0.70379       0.53576E-02
  13.100          68.523          0.70876       0.58992E-02
  13.200          69.472          0.71858       0.65547E-02
  13.300          70.254          0.72666       0.69998E-02
  13.400          70.719          0.73147       0.71090E-02
  13.500          71.791          0.74256       0.74504E-02
  13.600          72.548          0.75039       0.74339E-02
  13.700          73.297          0.75813       0.72426E-02
  13.800          74.332          0.76884       0.72238E-02
  13.900          75.353          0.77941       0.71687E-02
  14.000          76.218          0.78835       0.69061E-02
```

```
YPOSITION          U            U/UE          CTAU
  14.100        77.214        0.79866      0.66503E-02
  14.200        77.918        0.80594      0.60524E-02
  14.300        78.893        0.81602      0.57613E-02
  14.400        79.582        0.82315      0.51411E-02
  14.500        80.672        0.83442      0.50012E-02
  14.600        81.881        0.84693      0.49874E-02
  14.700        82.810        0.85653      0.45878E-02
  14.800        83.597        0.86468      0.39863E-02
  14.900        84.248        0.87140      0.31841E-02
  15.000        85.022        0.87941      0.26050E-02
  15.100        85.916        0.88866      0.22577E-02
  15.200        86.675        0.89651      0.17159E-02
  15.300        87.553        0.90559      0.14039E-02
  15.400        87.926        0.90945      0.22751E-03
  15.500        88.668        0.91713     -0.19467E-03
  15.600        89.526        0.92600     -0.31501E-03
  15.700        90.255        0.93354     -0.64373E-03
  15.800        90.497        0.93604     -0.19402E-02
  15.900        91.098        0.94226     -0.23913E-02
  16.000        91.814        0.94967     -0.25159E-02
  16.100        92.407        0.95580     -0.28436E-02
  16.200        93.113        0.96310      0.86445E-03
  16.300        93.464        0.96674      0.74734E-02
```

```
YPOSITION          U            U/UE          CTAU
  16.400         94.047       0.97276     0.14685E-01
  16.500         94.394       0.97636     0.21579E-01
  16.600         94.971       0.98232     0.29013E-01
  16.700         95.315       0.98588     0.36189E-01
  16.800         95.430       0.98707     0.43153E-01
  16.900         95.772       0.99061     0.50521E-01
  17.000         96.114       0.99414     0.57989E-01
  17.100         96.454       0.99766     0.65534E-01
  17.200         96.680        1.0000     0.73081E-01
```

```
                  AXIAL STATION 6OUT OF11STATIONS

            DELSTAR= 0.82007E-01     THETA= 0.61036E-01
              SHAPE=  1.3436          EPSILON=-0.45972


  YPOSITION         U             U/UE           CTAU
   7.0000        88.668          1.0000       0.21442E-01
   7.1000        88.298         0.99582       0.14304E-01
   7.2000        87.802         0.99023       0.10441E-01
   7.3000        87.303         0.98460       0.10802E-01
   7.4000        86.801         0.97894       0.10953E-01
   7.5000        86.549         0.97610       0.11374E-01
   7.6000        86.043         0.97039       0.11416E-01
   7.7000        85.916         0.96896       0.11314E-01
   7.8000        85.278         0.96177       0.11695E-01
   7.9000        84.893         0.95743       0.11851E-01
   8.0000        84.248         0.95015       0.11767E-01
   8.1000        83.858         0.94575       0.11917E-01
   8.2000        83.204         0.93838       0.11910E-01
   8.3000        82.810         0.93393       0.12130E-01
   8.4000        82.413         0.92946       0.12167E-01
```

```
YPOSITION           U            U/UE           CTAU
  8.5000         81.614       0.92045      0.12165E-01
  8.6000         81.212       0.91591      0.12339E-01
  8.7000         80.537       0.90830      0.12359E-01
  8.8000         79.856       0.90062      0.12394E-01
  8.9000         79.031       0.89132      0.12211E-01
  9.0000         78.477       0.88506      0.11825E-01
  9.1000         77.778       0.87718      0.11492E-01
  9.2000         77.214       0.87082      0.11494E-01
  9.3000         76.647       0.86442      0.11451E-01
  9.4000         75.931       0.85635      0.11079E-01
  9.5000         75.353       0.84984      0.10962E-01
  9.6000         74.479       0.83997      0.10839E-01
  9.7000         74.038       0.83500      0.10846E-01
  9.8000         73.297       0.82664      0.10551E-01
  9.9000         72.698       0.81989      0.10456E-01
  10.000         71.791       0.80966      0.10196E-01
  10.100         71.027       0.80104      0.99077E-02
  10.200         69.786       0.78705      0.94778E-02
  10.300         69.157       0.77996      0.90279E-02
  10.400         68.523       0.77280      0.87613E-02
  10.500         67.721       0.76376      0.84548E-02
  10.600         66.910       0.75461      0.82124E-02
  10.700         65.924       0.74349      0.78351E-02
```

```
YPOSITION        U           U/UE          CTAU
  10.800       65.258       0.73598       0.74000E-02
  10.900       64.754       0.73030       0.69317E-02
  11.000       64.076       0.72265       0.64454E-02
  11.100       63.045       0.71102       0.60206E-02
  11.200       62.523       0.70514       0.55181E-02
  11.300       61.821       0.69722       0.48194E-02
  11.400       61.289       0.69121       0.42327E-02
  11.500       60.752       0.68516       0.37085E-02
  11.600       59.846       0.67495       0.30982E-02
  11.700       59.112       0.66667       0.24981E-02
  11.800       58.927       0.66458       0.18643E-02
  11.900       58.368       0.65828       0.12487E-02
  12.000       58.368       0.65828       0.63569E-03
  12.100       58.368       0.65828       0.0
  12.200       58.368       0.65828       0.63569E-03
  12.300       58.368       0.65828       0.12487E-02
  12.400       58.368       0.65828       0.18643E-02
  12.500       58.368       0.65828       0.24981E-02
  12.600       58.368       0.65828       0.30982E-02
  12.700       58.741       0.66249       0.37085E-02
  12.800       58.741       0.66249       0.42327E-02
  12.900       59.112       0.66667       0.48194E-02
  13.000       60.029       0.67700       0.55181E-02
```

```
  YPOSITION              U                U/UE               CTAU
    13.100            60.391            0.68109          0.60206E-02
    13.200            60.572            0.68313          0.64454E-02
    13.300            61.110            0.68920          0.69317E-02
    13.400            61.821            0.69722          0.74000E-02
    13.500            62.523            0.70514          0.78351E-02
    13.600            63.218            0.71297          0.82124E-02
    13.700            63.734            0.71880          0.84548E-02
    13.800            64.416            0.72648          0.87613E-02
    13.900            65.090            0.73409          0.90279E-02
    14.000            66.089            0.74536          0.94778E-02
    14.100            67.073            0.75645          0.99077E-02
    14.200            67.882            0.76558          0.10196E-01
    14.300            68.682            0.77460          0.10456E-01
    14.400            69.315            0.78174          0.10551E-01
    14.500            70.254            0.79232          0.10846E-01
    14.600            70.873            0.79931          0.10839E-01
    14.700            71.639            0.80795          0.10962E-01
    14.800            72.397            0.81650          0.11079E-01
    14.900            73.445            0.82832          0.11451E-01
    15.000            74.185            0.83666          0.11494E-01
    15.100            74.917            0.84492          0.11492E-01
    15.200            75.931            0.85635          0.11825E-01
    15.300            76.931            0.86763          0.12211E-01
```

```
  YPOSITION          U             U/UE            CTAU
    15.400        77.778         0.87718       0.12394E-01
    15.500        78.477         0.88506       0.12359E-01
    15.600        79.169         0.89287       0.12339E-01
    15.700        79.719         0.89907       0.12165E-01
    15.800        80.401         0.90676       0.12167E-01
    15.900        81.077         0.91439       0.12130E-01
    16.000        81.614         0.92045       0.11910E-01
    16.100        82.281         0.92796       0.11917E-01
    16.200        82.810         0.93393       0.11767E-01
    16.300        83.466         0.94133       0.11851E-01
    16.400        83.988         0.94722       0.11695E-01
    16.500        84.377         0.95161       0.11314E-01
    16.600        85.022         0.95888       0.11416E-01
    16.700        85.534         0.96465       0.11374E-01
    16.800        85.789         0.96753       0.10953E-01
    16.900        86.170         0.97183       0.10802E-01
    17.000        86.423         0.97468       0.10441E-01
    17.100        86.927         0.98036       0.14304E-01
    17.200        87.178         0.98319       0.21442E-01
    17.300        87.553         0.98742       0.28880E-01
    17.400        87.802         0.99023       0.36230E-01
    17.500        87.926         0.99163       0.43491E-01
    17.600        88.174         0.99443       0.50901E-01
```

```
  YPOSITION          U             U/UE          CTAU
    17.700         88.298        0.99582      0.58261E-01
    17.800         88.298        0.99582      0.65568E-01
    17.900         88.298        0.99582      0.72874E-01
    18.000         88.298        0.99582      0.80150E-01
```

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                    AXIAL STATION 7OUT OF11STATIONS


           DELSTAR= 0.79455E-01     THETA= 0.59835E-01
             SHAPE=  1.3279        EPSILON= -2.9388


   YPOSITION           U              U/UE              CTAU
     6.7000          82.148          0.99201         -0.12377E-02
     6.8000          82.148          0.99201         -0.23824E-03
     6.9000          82.148          0.99201          0.71903E-03
     7.0000          82.015          0.99040          0.16487E-02
     7.1000          81.748          0.98718          0.23760E-02
     7.2000          81.480          0.98395          0.30282E-02
     7.3000          81.212          0.98071          0.35627E-02
     7.4000          80.808          0.97582          0.40229E-02
     7.5000          80.537          0.97255          0.44790E-02
     7.6000          79.993          0.96598          0.49555E-02
     7.7000          79.582          0.96102          0.53310E-02
     7.8000          79.169          0.95604          0.57110E-02
     7.9000          78.754          0.95103          0.61139E-02
     8.0000          78.616          0.94935          0.64920E-02
     8.1000          77.918          0.94093          0.68763E-02
```

```
YPOSITION          U              U/UE           CTAU
  8.2000         77.356         0.93414       0.72368E-02
  8.3000         76.931         0.92901       0.75094E-02
  8.4000         76.218         0.92040       0.78274E-02
  8.5000         75.787         0.91519       0.81003E-02
  8.6000         75.353         0.90996       0.83832E-02
  8.7000         75.063         0.90645       0.86918E-02
  8.8000         74.332         0.89763       0.90085E-02
  8.9000         73.147         0.88332       0.92563E-02
  9.0000         72.848         0.87971       0.94651E-02
  9.1000         71.943         0.86878       0.96519E-02
  9.2000         71.487         0.86326       0.97304E-02
  9.3000         70.719         0.85399       0.97174E-02
  9.4000         70.098         0.84650       0.97541E-02
  9.5000         69.472         0.83894       0.97935E-02
  9.6000         68.999         0.83323       0.98120E-02
  9.7000         68.203         0.82362       0.98067E-02
  9.8000         67.236         0.81193       0.97918E-02
  9.9000         66.419         0.80207       0.97507E-02
  10.000         65.592         0.79208       0.96684E-02
  10.100         64.922         0.78400       0.95211E-02
  10.200         64.076         0.77377       0.93578E-02
  10.300         63.391         0.76550       0.91779E-02
  10.400         62.698         0.75713       0.89408E-02
```

```
YPOSITION           U            U/UE            CTAU
  10.500         62.173       0.75080       0.86147E-02
  10.600         61.467       0.74226       0.82760E-02
  10.700         60.572       0.73146       0.79241E-02
  10.800         59.846       0.72270       0.75584E-02
  10.900         59.112       0.71383       0.72158E-02
  11.000         58.368       0.70485       0.68307E-02
  11.100         57.993       0.70032       0.63364E-02
  11.200         57.615       0.69576       0.57592E-02
  11.300         57.235       0.69116       0.51747E-02
  11.400         56.660       0.68422       0.46513E-02
  11.500         55.884       0.67484       0.41139E-02
  11.600         55.688       0.67248       0.35491E-02
  11.700         55.294       0.66773       0.30172E-02
  11.800         55.096       0.66534       0.24857E-02
  11.900         54.898       0.66294       0.19563E-02
  12.000         54.898       0.66294       0.14557E-02
  12.100         54.499       0.65812       0.96901E-03
  12.200         54.298       0.65570       0.48494E-03
  12.300         54.699       0.66053       0.0
  12.400         54.898       0.66294       0.48494E-03
  12.500         54.699       0.66053       0.96901E-03
  12.600         55.096       0.66534       0.14557E-02
  12.700         55.294       0.66773       0.19563E-02
```

```
YPOSITION         U           U/UE          CTAU
  12.800        55.294      0.66773      0.24857E-02
  12.900        55.491      0.67011      0.30172E-02
  13.000        55.688      0.67248      0.35491E-02
  13.100        56.079      0.67720      0.41139E-02
  13.200        56.660      0.68422      0.46513E-02
  13.300        57.235      0.69116      0.51747E-02
  13.400        57.805      0.69804      0.57592E-02
  13.500        57.993      0.70032      0.63364E-02
  13.600        58.741      0.70936      0.68307E-02
  13.700        59.297      0.71606      0.72158E-02
  13.800        59.846      0.72270      0.75584E-02
  13.900        60.572      0.73146      0.79241E-02
  14.000        61.289      0.74012      0.82760E-02
  14.100        61.997      0.74867      0.86147E-02
  14.200        62.698      0.75713      0.89408E-02
  14.300        63.391      0.76550      0.91779E-02
  14.400        64.076      0.77377      0.93578E-02
  14.500        64.922      0.78400      0.95211E-02
  14.600        65.924      0.79609      0.96684E-02
  14.700        66.583      0.80405      0.97507E-02
  14.800        67.236      0.81193      0.97918E-02
  14.900        67.882      0.81974      0.98067E-02
  15.000        68.523      0.82747      0.98120E-02
```

```
YPOSITION          U             U/UE            CTAU
  15.100        69.157         0.83514        0.97935E-02
  15.200        69.942         0.84462        0.97541E-02
  15.300        70.564         0.85212        0.97174E-02
  15.400        71.487         0.86326        0.97304E-02
  15.500        72.246         0.87244        0.96519E-02
  15.600        72.848         0.87971        0.94651E-02
  15.700        73.445         0.88692        0.92563E-02
  15.800        74.038         0.89407        0.90085E-02
  15.900        74.479         0.89940        0.86918E-02
  16.000        74.917         0.90469        0.83832E-02
  16.100        75.498         0.91171        0.81003E-02
  16.200        76.218         0.92040        0.78274E-02
  16.300        76.789         0.92729        0.75094E-02
  16.400        77.497         0.93584        0.72368E-02
  16.500        77.918         0.94093        0.68763E-02
  16.600        78.337         0.94599        0.64920E-02
  16.700        78.754         0.95103        0.61139E-02
  16.800        79.169         0.95604        0.57110E-02
  16.900        79.856         0.96433        0.53310E-02
  17.000        80.537         0.97255        0.49555E-02
  17.100        80.808         0.97582        0.44790E-02
  17.200        81.077         0.97908        0.40229E-02
  17.300        81.480         0.98395        0.35627E-02
```

```
YPOSITION          U             U/UE           CTAU
  17.400        81.881         0.98879      0.30282E-02
  17.500        82.148         0.99201      0.23760E-02
  17.600        82.413         0.99521      0.16487E-02
  17.700        82.413         0.99521      0.71903E-03
  17.800        82.545         0.99681     -0.23824E-03
  17.900        82.810          1.0000     -0.12377E-02
  18.000        82.545         0.99681     -0.26319E-02
  18.100        82.678         0.99841     -0.68925E-02
  18.200        82.281         0.99361     -0.14543E-01
  18.300        81.748         0.98718     -0.18756E-01
  18.400        81.480         0.98395     -0.19046E-01
  18.500        80.129         0.96763     -0.20509E-01
```

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                    AXIAL STATION 8OUT OF11STATIONS


            DELSTAR= 0.67435E-01     THETA= 0.52687E-01
              SHAPE=   1.2799          EPSILON= 0.30954


   YPOSITION          U              U/UE            CTAU
    7.3000          81.614           1.0000      -0.63340E-01
    7.4000          81.346          0.99672      -0.57170E-01
    7.5000          81.077          0.99342      -0.51119E-01
    7.6000          80.672          0.98846      -0.45193E-01
    7.7000          80.401          0.98514      -0.39580E-01
    7.8000          79.993          0.98013      -0.34114E-01
    7.9000          79.719          0.97678      -0.28668E-01
    8.0000          79.169          0.97004      -0.23192E-01
    8.1000          78.754          0.96496      -0.19844E-01
    8.2000          78.198          0.95814      -0.18900E-01
    8.3000          77.637          0.95127      -0.17841E-01
    8.4000          77.073          0.94435      -0.16883E-01
    8.5000          76.647          0.93913      -0.16001E-01
    8.6000          76.218          0.93388      -0.14916E-01
    8.7000          75.787          0.92860      -0.14019E-01
```

```
YPOSITION          U             U/UE            CTAU
  8.8000         75.063        0.91973       -0.13131E-01
  8.9000         74.625        0.91437       -0.12242E-01
  9.0000         74.038        0.90717       -0.11520E-01
  9.1000         73.297        0.89809       -0.10844E-01
  9.2000         72.698        0.89075       -0.99374E-02
  9.3000         72.397        0.88707       -0.90598E-02
  9.4000         71.943        0.88150       -0.81930E-02
  9.5000         71.334        0.87403       -0.74942E-02
  9.6000         70.564        0.86460       -0.66464E-02
  9.7000         69.942        0.85699       -0.59595E-02
  9.8000         69.315        0.84930       -0.52870E-02
  9.9000         68.682        0.84154       -0.46414E-02
  10.000         67.882        0.83175       -0.41782E-02
  10.100         67.073        0.82183       -0.37672E-02
  10.200         66.419        0.81381       -0.32632E-02
  10.300         65.592        0.80368       -0.28685E-02
  10.400         65.258        0.79959       -0.23475E-02
  10.500         64.754        0.79342       -0.17450E-02
  10.600         64.076        0.78511       -0.14166E-02
  10.700         63.218        0.77460       -0.10489E-02
  10.800         62.523        0.76608       -0.79692E-03
  10.900         62.173        0.76179       -0.80793E-03
  11.000         61.467        0.75314       -0.73721E-03
```

```
 YPOSITION          U            U/UE          CTAU
   11.100         61.289        0.75096     -0.58493E-03
   11.200         60.931        0.74658     -0.35559E-03
   11.300         60.391        0.73996     -0.88427E-04
   11.400         59.846        0.73328     -0.21659E-04
   11.500         59.112        0.72429      0.52478E-04
   11.600         58.741        0.71975      0.61218E-04
   11.700         58.368        0.71518      0.89787E-04
   11.800         57.993        0.71058      0.11539E-03
   11.900         57.805        0.70827      0.12397E-03
   12.000         57.615        0.70595      0.90204E-04
   12.100         57.615        0.70595      0.53299E-04
   12.200         57.615        0.70595      0.0
   12.300         57.615        0.70595      0.53299E-04
   12.400         57.615        0.70595      0.90204E-04
   12.500         57.615        0.70595      0.12397E-03
   12.600         57.805        0.70827      0.11539E-03
   12.700         57.993        0.71058      0.89787E-04
   12.800         58.181        0.71288      0.61218E-04
   12.900         58.368        0.71518      0.52478E-04
   13.000         58.927        0.72202     -0.21659E-04
   13.100         59.297        0.72655     -0.88427E-04
   13.200         60.029        0.73552     -0.35559E-03
   13.300         60.572        0.74217     -0.58493E-03
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```
 YPOSITION            U              U/UE            CTAU
   13.400          60.931          0.74658      -0.73721E-03
   13.500          61.110          0.74877      -0.80793E-03
   13.600          61.110          0.74877      -0.79692E-03
   13.700          61.644          0.75531      -0.10489E-02
   13.800          62.349          0.76394      -0.14166E-02
   13.900          62.872          0.77035      -0.17450E-02
   14.000          63.734          0.78092      -0.23475E-02
   14.100          64.416          0.78927      -0.28685E-02
   14.200          64.922          0.79548      -0.32632E-02
   14.300          65.592          0.80368      -0.37672E-02
   14.400          66.089          0.80978      -0.41782E-02
   14.500          66.583          0.81583      -0.46414E-02
   14.600          67.236          0.82383      -0.52870E-02
   14.700          67.882          0.83175      -0.59595E-02
   14.800          68.523          0.83959      -0.66464E-02
   14.900          69.315          0.84930      -0.74942E-02
   15.000          69.942          0.85699      -0.81930E-02
   15.100          70.719          0.86650      -0.90598E-02
   15.200          71.487          0.87591      -0.99374E-02
   15.300          72.246          0.88522      -0.10844E-01
   15.400          72.698          0.89075      -0.11520E-01
   15.500          73.147          0.89626      -0.12242E-01
   15.600          73.742          0.90354      -0.13131E-01
```

```
YPOSITION          U           U/UE          CTAU
  15.700        74.332       0.91077     -0.14019E-01
  15.800        74.917       0.91795     -0.14916E-01
  15.900        75.643       0.92683     -0.16001E-01
  16.000        76.218       0.93388     -0.16883E-01
  16.100        76.789       0.94088     -0.17841E-01
  16.200        77.356       0.94782     -0.18900E-01
  16.300        77.778       0.95299     -0.19844E-01
  16.400        78.337       0.95985     -0.23192E-01
  16.500        78.893       0.96666     -0.28668E-01
  16.600        79.307       0.97173     -0.34114E-01
  16.700        79.582       0.97510     -0.39580E-01
  16.800        79.856       0.97846     -0.45193E-01
  16.900        80.537       0.98680     -0.51119E-01
  17.000        80.943       0.99177     -0.57170E-01
  17.100        81.212       0.99507     -0.63340E-01
  17.200        81.212       0.99507     -0.69717E-01
  17.300        81.346       0.99672     -0.76122E-01
  17.400        81.346       0.99672     -0.82760E-01
  17.500        81.346       0.99672     -0.89497E-01
  17.600        81.346       0.99672     -0.96298E-01
  17.700        81.212       0.99507     -0.10335
  17.800        80.808       0.99012     -0.11096
  17.900        80.265       0.98347     -0.11888
```

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                     AXIAL STATION 9OUT OF11STATIONS


               DELSTAR= 0.47823E-01     THETA= 0.39288E-01
                 SHAPE=  1.2173          EPSILON= 0.48032E-01



     YPOSITION            U              U/UE           CTAU
       7.7000          87.926          1.0000       -0.39580E-01
       7.8000          87.802          0.99859      -0.34114E-01
       7.9000          87.802          0.99859      -0.28668E-01
       8.0000          87.802          0.99859      -0.23192E-01
       8.1000          87.553          0.99575      -0.40279E-01
       8.2000          87.178          0.99149      -0.34131E-01
       8.3000          86.675          0.98577      -0.28353E-01
       8.4000          86.297          0.98147      -0.22974E-01
       8.5000          85.916          0.97714      -0.16867E-01
       8.6000          85.662          0.97424      -0.13105E-01
       8.7000          85.150          0.96843      -0.12416E-01
       8.8000          84.506          0.96111      -0.11289E-01
       8.9000          83.858          0.95373      -0.10272E-01
       9.0000          83.335          0.94779      -0.92452E-02
       9.1000          82.810          0.94181      -0.88272E-02
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```
YPOSITION        U          U/UE          CTAU
  9.2000       82.148      0.93428     -0.78797E-02
  9.3000       81.614      0.92821     -0.70323E-02
  9.4000       80.943      0.92057     -0.65540E-02
  9.5000       80.265      0.91287     -0.55940E-02
  9.6000       79.582      0.90510     -0.49410E-02
  9.7000       78.893      0.89727     -0.43205E-02
  9.8000       78.198      0.88936     -0.39534E-02
  9.9000       77.778      0.88458     -0.38356E-02
  10.000       77.073      0.87656     -0.32520E-02
  10.100       76.504      0.87009     -0.28734E-02
  10.200       75.787      0.86194     -0.25036E-02
  10.300       75.208      0.85536     -0.17242E-02
  10.400       74.479      0.84706     -0.11302E-02
  10.500       73.890      0.84037     -0.95594E-03
  10.600       73.147      0.83192     -0.99051E-03
  10.700       72.698      0.82681     -0.69541E-03
  10.800       72.246      0.82167     -0.43559E-03
  10.900       71.791      0.81650     -0.16042E-03
  11.000       71.180      0.80955      0.59586E-04
  11.100       70.719      0.80430      0.20526E-03
  11.200       70.254      0.79901      0.46175E-03
  11.300       69.786      0.79369      0.56383E-03
  11.400       69.315      0.78833      0.62771E-03
```

```
YPOSITION          U              U/UE           CTAU
  11.500          68.841         0.78294        0.74705E-03
  11.600          68.682         0.78113        0.91718E-03
  11.700          68.043         0.77387        0.85716E-03
  11.800          67.560         0.76837        0.70577E-03
  11.900          67.398         0.76653        0.52145E-03
  12.000          67.236         0.76469        0.36699E-03
  12.100          67.236         0.76469        0.18904E-03
  12.200          67.236         0.76469        0.0
  12.300          67.236         0.76469        0.18904E-03
  12.400          67.236         0.76469        0.36699E-03
  12.500          67.398         0.76653        0.52145E-03
  12.600          67.398         0.76653        0.70577E-03
  12.700          67.398         0.76653        0.85716E-03
  12.800          67.560         0.76837        0.91718E-03
  12.900          68.203         0.77569        0.74705E-03
  13.000          68.682         0.78113        0.62771E-03
  13.100          68.999         0.78474        0.56383E-03
  13.200          69.315         0.78833        0.46175E-03
  13.300          69.786         0.79369        0.20526E-03
  13.400          70.098         0.79724        0.59586E-04
  13.500          70.564         0.80254       -0.16042E-03
  13.600          71.180         0.80955       -0.43559E-03
  13.700          71.791         0.81650       -0.69541E-03
```

```
    YPOSITION          U              U/UE            CTAU
      13.800         72.397         0.82339      -0.99051E-03
      13.900         72.698         0.82681      -0.95594E-03
      14.000         73.147         0.83192      -0.11302E-02
      14.100         73.890         0.84037      -0.17242E-02
      14.200         74.771         0.85039      -0.25036E-02
      14.300         75.353         0.85701      -0.28734E-02
      14.400         75.931         0.86358      -0.32520E-02
      14.500         76.647         0.87172      -0.38356E-02
      14.600         77.073         0.87656      -0.39534E-02
      14.700         77.637         0.88298      -0.43205E-02
      14.800         78.337         0.89095      -0.49410E-02
      14.900         79.031         0.89884      -0.55940E-02
      15.000         79.856         0.90822      -0.65540E-02
      15.100         80.401         0.91442      -0.70323E-02
      15.200         81.077         0.92211      -0.78797E-02
      15.300         81.748         0.92973      -0.88272E-02
      15.400         82.148         0.93428      -0.92452E-02
      15.500         82.810         0.94181      -0.10272E-01
      15.600         83.466         0.94928      -0.11289E-01
      15.700         84.118         0.95669      -0.12416E-01
      15.800         84.506         0.96111      -0.13105E-01
      15.900         85.150         0.96843      -0.16867E-01
      16.000         85.789         0.97569      -0.22974E-01
```

```
YPOSITION        U           U/UE          CTAU
  16.100       86.043      0.97858     -0.28353E-01
  16.200       86.423      0.98290     -0.34131E-01
  16.300       86.927      0.98864     -0.40279E-01
```

```
                    AXIAL STATION10OUT OF11STATIONS


               DELSTAR= 0.26115E-01      THETA= 0.23054E-01
                 SHAPE=  1.1328          EPSILON= 0.17211


  YPOSITION           U               U/UE              CTAU
   8.9000          100.34            1.0000        -0.15654E-02
   9.0000          100.12           0.99783        -0.99975E-03
   9.1000          99.902           0.99565        -0.50849E-03
   9.2000          99.683           0.99347         0.12028E-03
   9.3000          99.134           0.98800         0.67192E-03
   9.4000          98.692           0.98360         0.11427E-02
   9.5000          98.249           0.97918         0.15293E-02
   9.6000          97.692           0.97362         0.18550E-02
   9.7000          97.131           0.96804         0.21310E-02
   9.8000          96.454           0.96129         0.23839E-02
   9.9000          95.886           0.95563         0.29671E-02
   10.000          95.315           0.94994         0.33507E-02
   10.100          94.625           0.94306         0.35611E-02
   10.200          94.047           0.93730         0.37251E-02
   10.300          93.230           0.92916         0.38268E-02
```

```
YPOSITION         U           U/UE          CTAU
  10.400        92.525      0.92213      0.39259E-02
  10.500        91.933      0.91623      0.40628E-02
  10.600        91.337      0.91029      0.42053E-02
  10.700        90.858      0.90551      0.41941E-02
  10.800        90.376      0.90071      0.42588E-02
  10.900        89.770      0.89467      0.42878E-02
  11.000        89.159      0.88859      0.41045E-02
  11.100        88.545      0.88246      0.39099E-02
  11.200        87.802      0.87506      0.36179E-02
  11.300        87.052      0.86759      0.33376E-02
  11.400        86.801      0.86509      0.30554E-02
  11.500        86.423      0.86132      0.26738E-02
  11.600        86.297      0.86006      0.22193E-02
  11.700        86.043      0.85753      0.17785E-02
  11.800        85.789      0.85500      0.13468E-02
  11.900        85.662      0.85373      0.92727E-03
  12.000        85.662      0.85373      0.45930E-03
  12.100        85.662      0.85373      0.0
  12.200        85.662      0.85373      0.45930E-03
  12.300        85.534      0.85246      0.92727E-03
  12.400        85.662      0.85373      0.13468E-02
  12.500        85.662      0.85373      0.17785E-02
  12.600        85.662      0.85373      0.22193E-02
```

```
YPOSITION          U             U/UE           CTAU
  12.700         85.662         0.85373       0.26738E-02
  12.800         85.789         0.85500       0.30554E-02
  12.900         86.043         0.85753       0.33376E-02
  13.000         86.297         0.86006       0.36179E-02
  13.100         86.549         0.86257       0.39099E-02
  13.200         86.927         0.86634       0.41045E-02
  13.300         87.303         0.87009       0.42878E-02
  13.400         87.926         0.87630       0.42588E-02
  13.500         88.545         0.88246       0.41941E-02
  13.600         89.037         0.88737       0.42053E-02
  13.700         89.648         0.89346       0.40628E-02
  13.800         90.255         0.89951       0.39259E-02
  13.900         90.858         0.90551       0.38268E-02
  14.000         91.457         0.91148       0.37251E-02
  14.100         92.052         0.91741       0.35611E-02
  14.200         92.643         0.92331       0.33507E-02
  14.300         93.347         0.93033       0.29671E-02
  14.400         94.163         0.93845       0.23839E-02
  14.500         94.741         0.94421       0.21310E-02
  14.600         95.315         0.94994       0.18550E-02
  14.700         95.886         0.95563       0.15293E-02
  14.800         96.454         0.96129       0.11427E-02
  14.900         97.019         0.96692       0.67192E-03
```

```
YPOSITION          U            U/UE           CTAU
  15.000         97.580       0.97251       0.12028E-03
  15.100         98.138       0.97807      -0.50849E-03
  15.200         98.582       0.98249      -0.99975E-03
  15.300         99.024       0.98690      -0.15654E-02
  15.400         99.574       0.99238      -0.24614E-02
  15.500         99.793       0.99456      -0.57225E-02
  15.600         100.01       0.99674      -0.12031E-01
  15.700         100.23       0.99891      -0.18452E-01
```

```
                    AXIAL STATION11OUT OF11STATIONS


              DELSTAR= 0.15577E-01      THETA= 0.14397E-01
                SHAPE=   1.0820          EPSILON= 0.29195



      YPOSITION          U             U/UE          CTAU
        9.3000         112.35         1.0000        0.0
        9.4000         112.25        0.99913        0.0
        9.5000         111.86        0.99567        0.0
        9.6000         111.38        0.99131        0.0
        9.7000         110.88        0.98694        0.0
        9.8000         110.39        0.98255        0.0
        9.9000         109.90        0.97813        0.0
        10.000         109.50        0.97459        0.0
        10.100         109.00        0.97014        0.0
        10.200         108.60        0.96657        0.0
        10.300         108.19        0.96298        0.0
        10.400         107.48        0.95667        0.0
        10.500         106.97        0.95214        0.0
        10.600         106.36        0.94667        0.0
        10.700         105.74        0.94118        0.0
```

```
YPOSITION            U             U/UE          CTAU
  10.800          105.23         0.93657        0.0
  10.900          104.81         0.93287        0.0
  11.000          104.39         0.92915        0.0
  11.100          103.97         0.92542        0.0
  11.200          103.66         0.92261        0.0
  11.300          103.34         0.91979        0.0
  11.400          103.02         0.91697        0.0
  11.500          102.70         0.91413        0.0
  11.600          102.39         0.91129        0.0
  11.700          102.06         0.90844        0.0
  11.800          101.74         0.90558        0.0
  11.900          101.53         0.90366        0.0
  12.000          101.42         0.90271        0.0
  12.100          101.42         0.90271        0.0
  12.200          101.42         0.90271        0.0
  12.300          101.42         0.90271        0.0
  12.400          101.42         0.90271        0.0
  12.500          101.42         0.90271        0.0
  12.600          101.42         0.90271        0.0
  12.700          101.53         0.90366        0.0
  12.800          101.74         0.90558        0.0
  12.900          101.96         0.90748        0.0
  13.000          102.28         0.91034        0.0
```

```
YPOSITION          U            U/UE          CTAU
  13.100         102.60        0.91319       0.0
  13.200         102.92        0.91602       0.0
  13.300         103.23        0.91885       0.0
  13.400         103.55        0.92167       0.0
  13.500         103.87        0.92448       0.0
  13.600         104.18        0.92729       0.0
  13.700         104.60        0.93101       0.0
  13.800         105.02        0.93472       0.0
  13.900         105.64        0.94026       0.0
  14.000         106.26        0.94576       0.0
  14.100         106.87        0.95123       0.0
  14.200         107.38        0.95577       0.0
  14.300         107.89        0.96028       0.0
  14.400         108.50        0.96567       0.0
  14.500         108.90        0.96925       0.0
  14.600         109.30        0.97281       0.0
  14.700         109.70        0.97636       0.0
  14.800         110.09        0.97990       0.0
  14.900         110.39        0.98255       0.0
  15.000         110.79        0.98606       0.0
  15.100         111.08        0.98869       0.0
  15.200         111.38        0.99131       0.0
  15.300         111.77        0.99480       0.0
```

```
YPOSITION        U          U/UE        CTAU
  15.400       111.86      0.99567     0.0
  15.500       111.86      0.99567     0.0
```

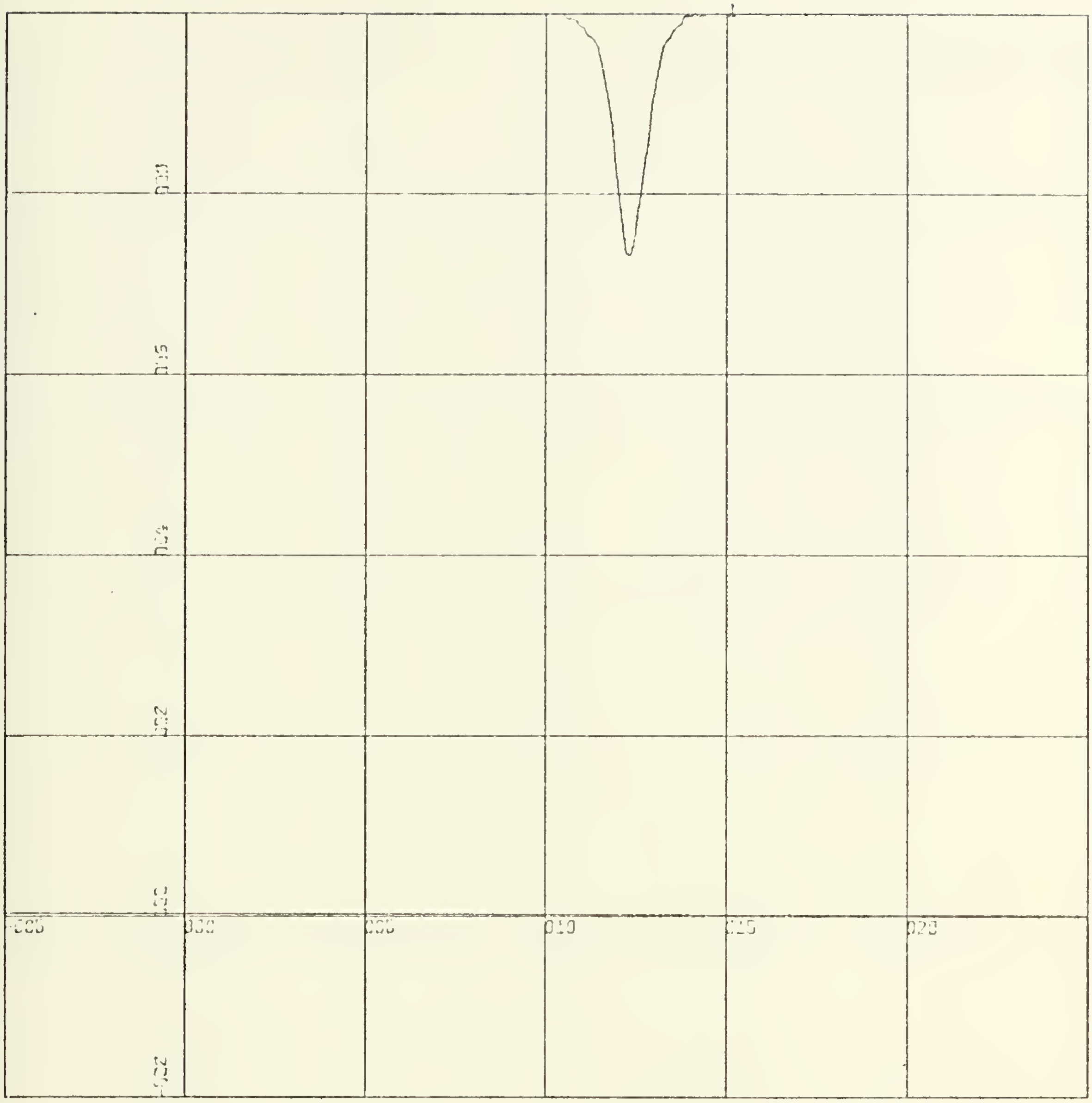
```
                         ***SUMMARY OF INTEGRATED WAKE PROPERTIES***

  AXIAL                                                                THETA
 STATION     X/D         DELSTAR        DELRATIO        THETA         RATIO        SHAPE
    1       3.8125     0.12447E-01      1.0000      0.10270E-01      1.0000       1.2120
    2       8.8125     0.19818E-01      1.5921      0.16468E-01      1.6034       1.2034
    3       13.812     0.29650E-01      2.3821      0.24545E-01      2.3898       1.2080
    4       18.812     0.40497E-01      3.2535      0.32596E-01      3.1738       1.2424
    5       23.813     0.62057E-01      4.9855      0.48019E-01      4.6754       1.2923
    6       28.812     0.82007E-01      6.5883      0.61036E-01      5.9429       1.3436
    7       33.812     0.79455E-01      6.3833      0.59835E-01      5.8259       1.3279
    8       38.813     0.67435E-01      5.4176      0.52687E-01      5.1299       1.2799
    9       43.812     0.47823E-01      3.8421      0.39288E-01      3.8253       1.2173
   10       48.812     0.26115E-01      2.0980      0.23054E-01      2.2447       1.1328
   11       53.813     0.15577E-01      1.2515      0.14397E-01      1.4017       1.0820
```

```
                         TURBULENCE CHECKS

STATION        ETA          MU(X)        EPSILON        MASS FLOW

    1        -0.9769       0.0424        0.5624          19.4819
    2        -0.9814       0.0289        0.5460          28.2630
    3        -0.9934       0.0118        0.1489          28.4597
    4        -1.0009      -0.0032       -0.0900          30.9617
    5        -1.0000      -0.0062       -0.0993          33.2085
    6        -1.0000      -0.0187       -0.4597          36.0769
    7        -1.0000      -0.0287       -2.9388          32.5661
    8        -1.0000      -0.0197        0.3095          31.6917
    9        -1.0000      -0.0092        0.0480          25.5959
   10        -1.0002      -0.0092        0.1721          28.0386
   11        -1.0000       0.0           0.2920          28.8358
```



Station 1

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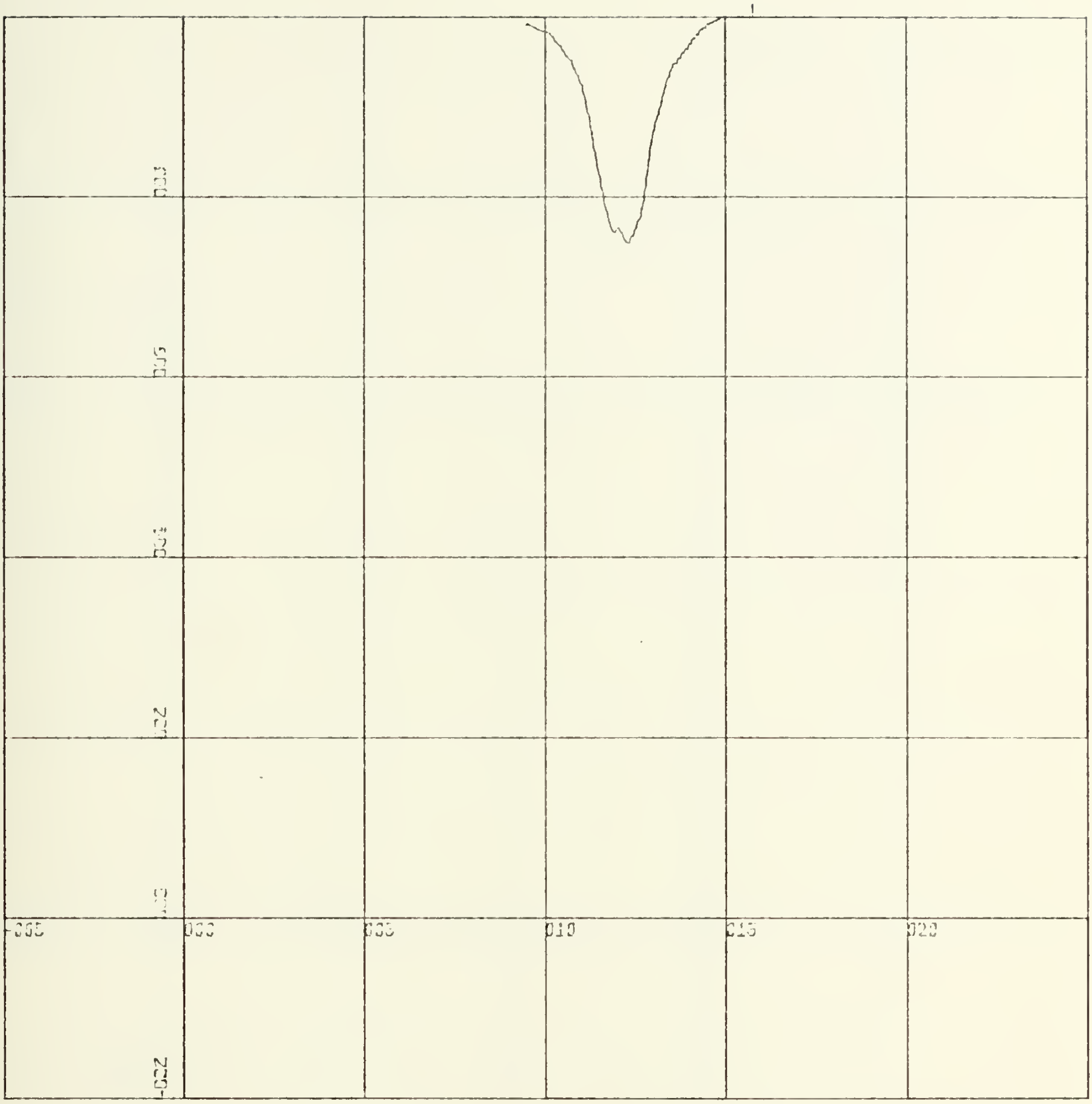
Y-SCALE=2.00E-01 UNITS INCH.

A PLOT OF THE PITOT-STATIC
VELOCITY RATIO VERSUS POSITION



Station 2

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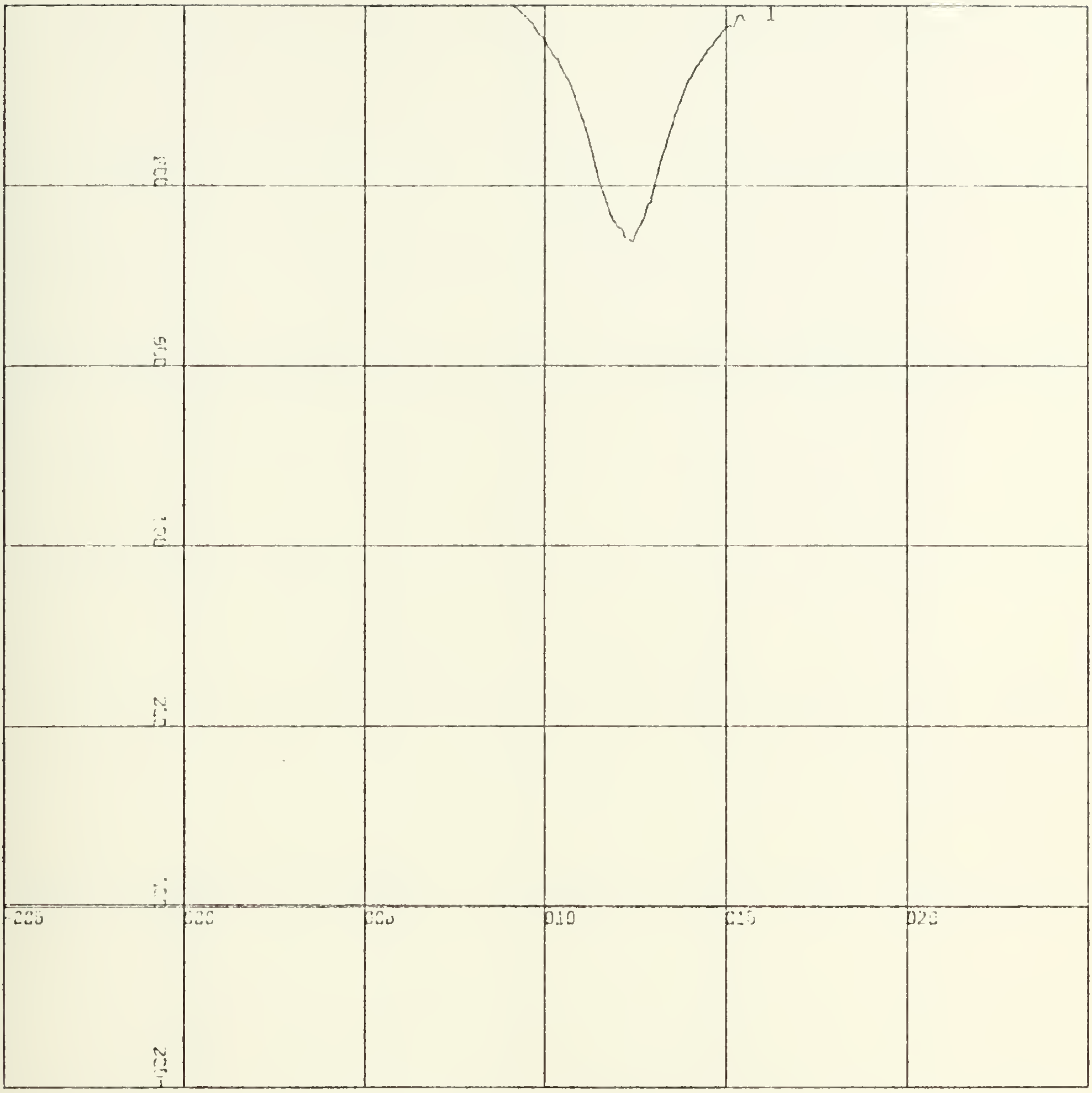
Y-SCALE=2.00E-01 UNITS INCH.

A PLOT OF THE PITOT-STATIC VELOCITY RATIO VERSUS POSITION



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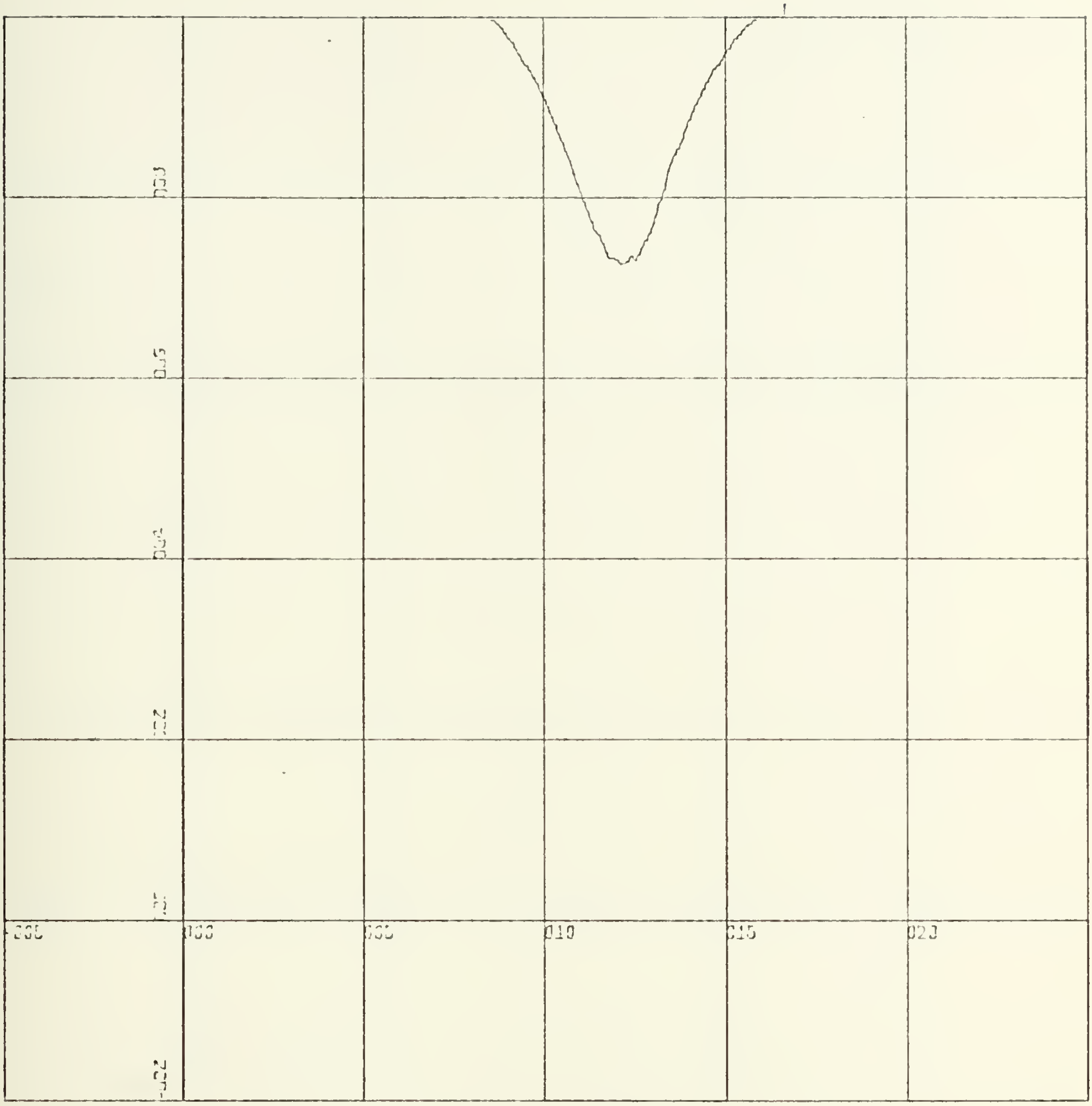
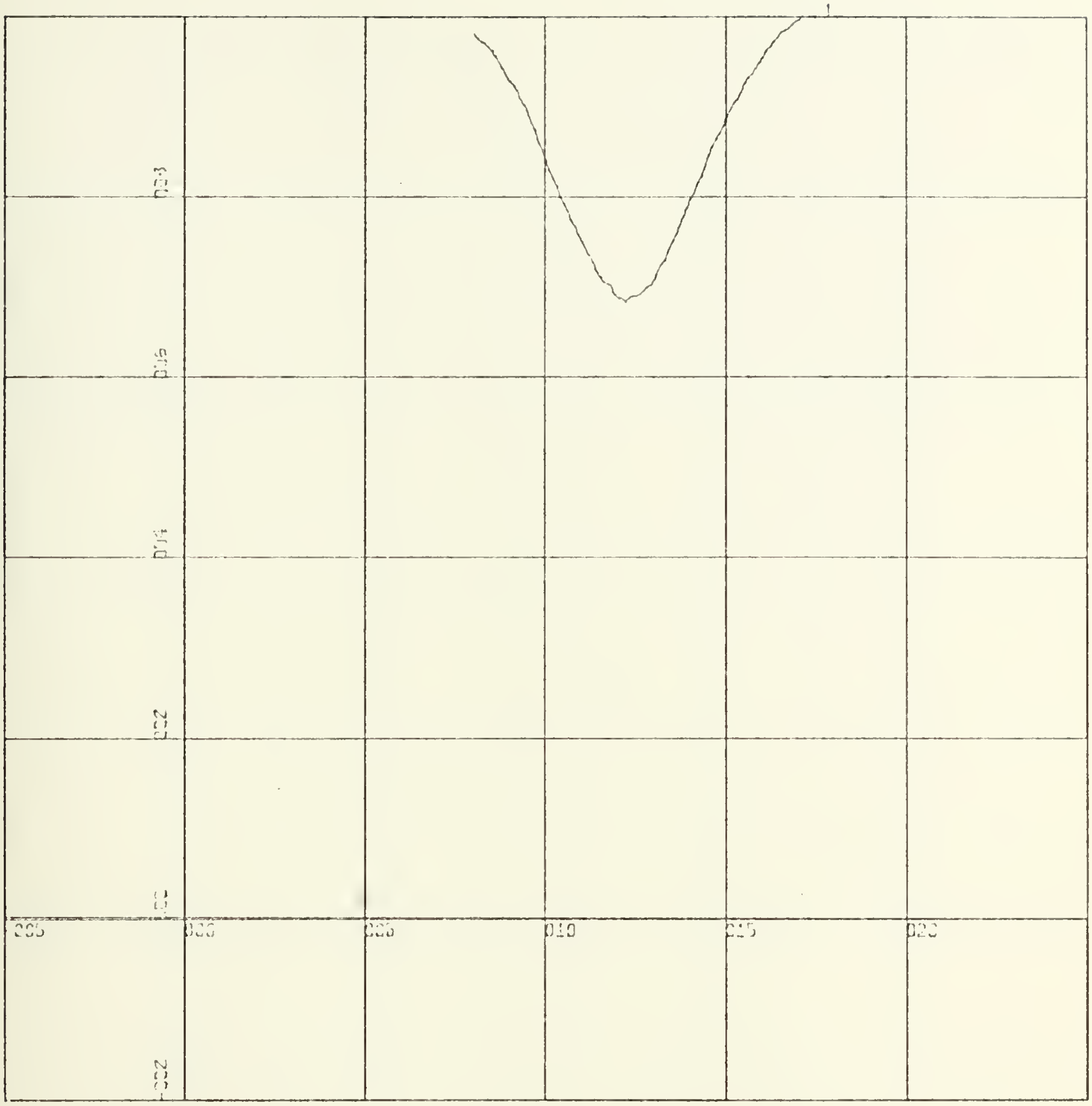


Station 4

X-SCALE=5.00E+00 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.

A PLOT OF THE PITOT-STATIC VELOCITY RATIO VERSUS POSITION



Station 5

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Y-SCALE=2.00E-01 UNITS INCH.

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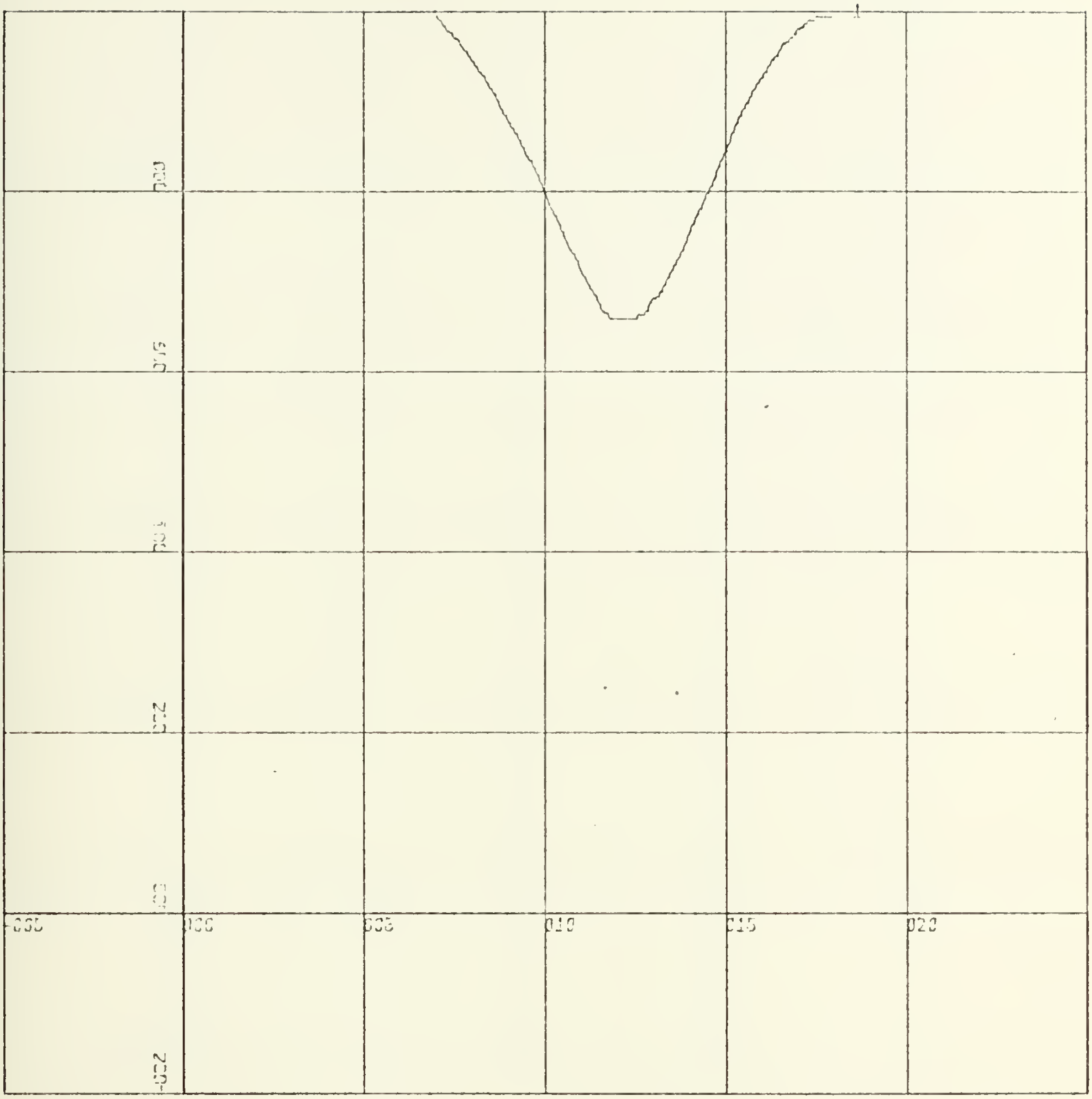
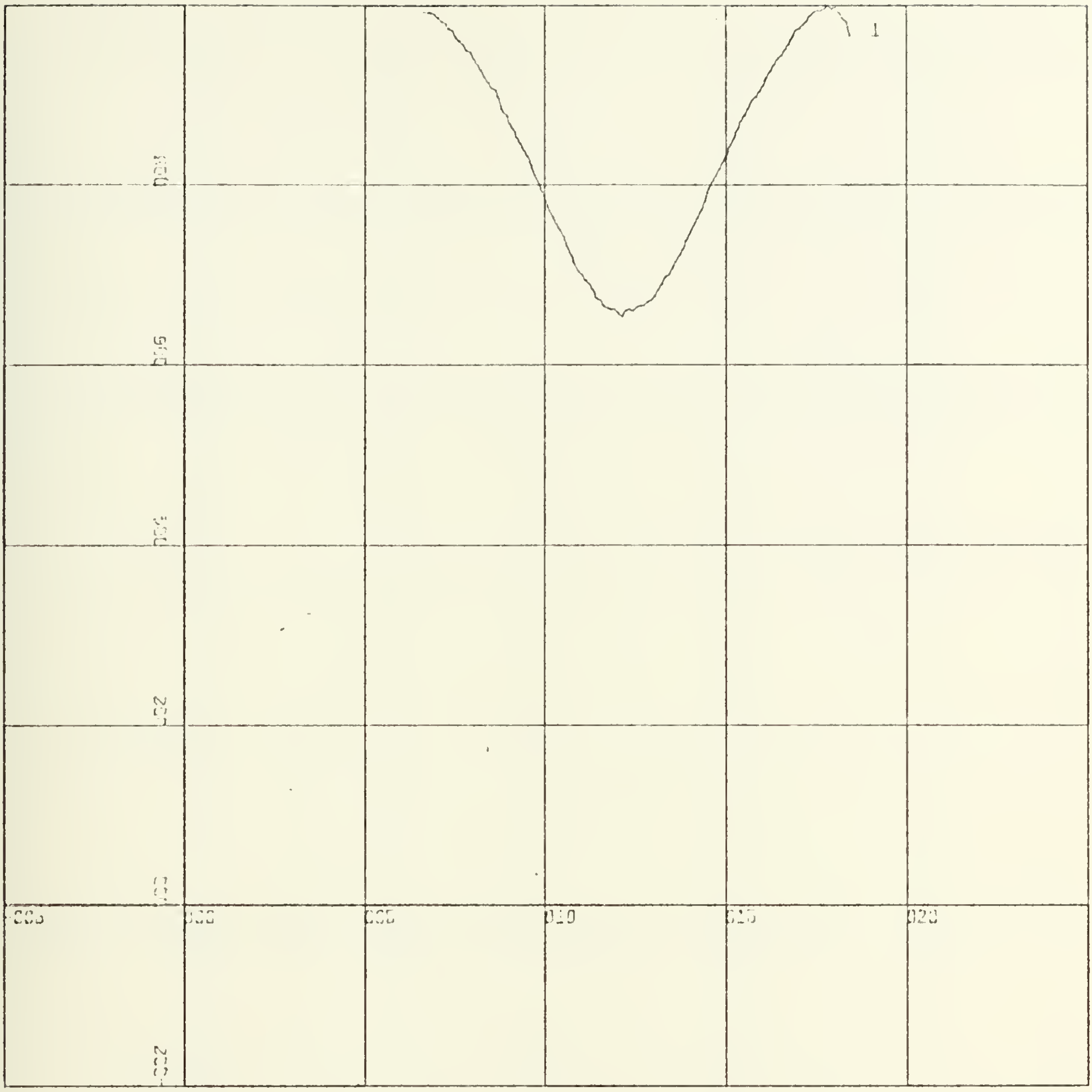


Station 6

X-SCALE=5.00E+00 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.

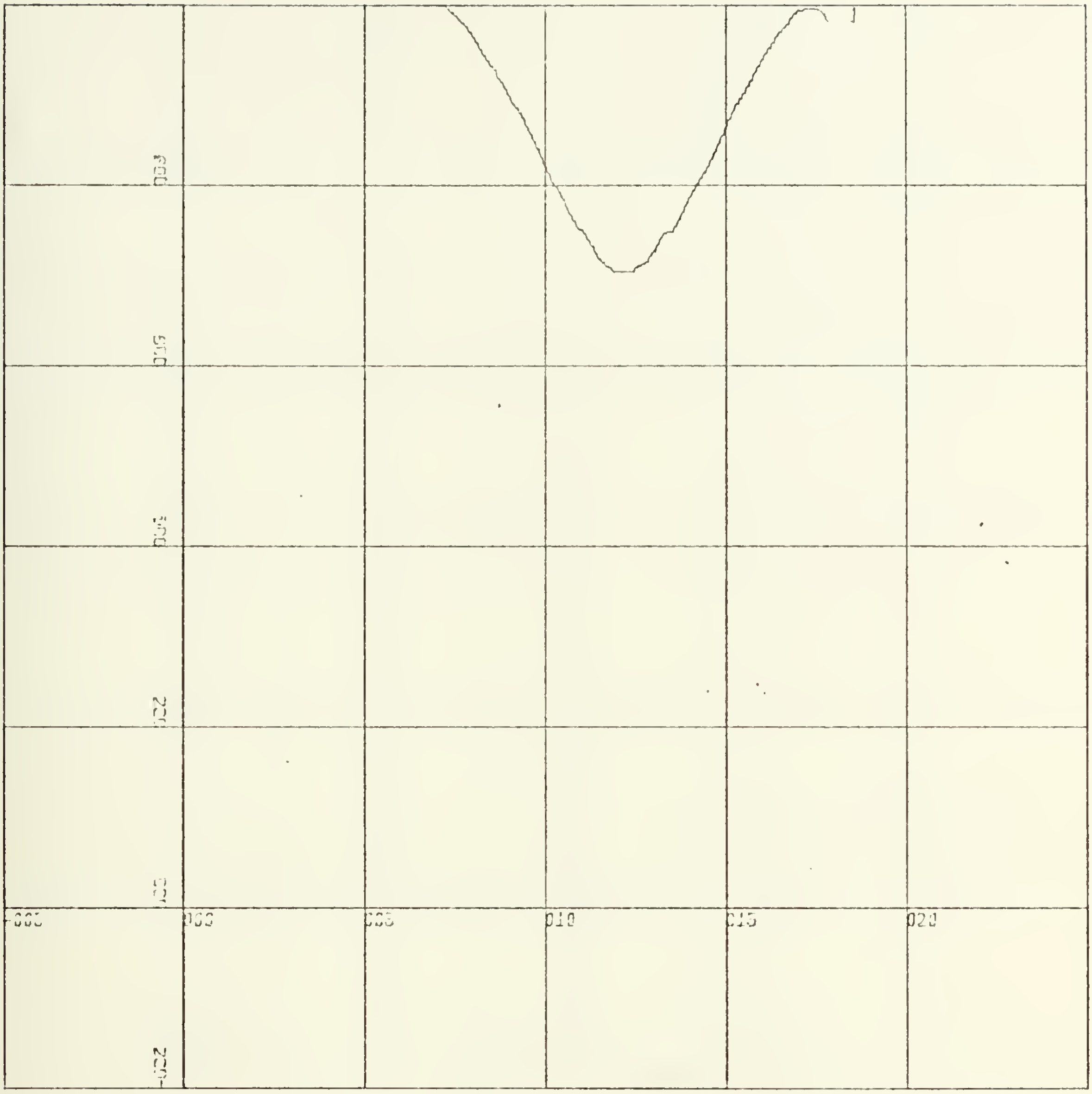
A PLOT OF THE PITOT-STATIC VELOCITY RATIO VERSUS POSITION



Station 7

X-SCALE=5.00E+00 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.

A PLOT OF THE PITOT-STATIC VELOCITY RATIO VERSUS POSITION



Station 8

X-SCALE=5.00E+00 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.
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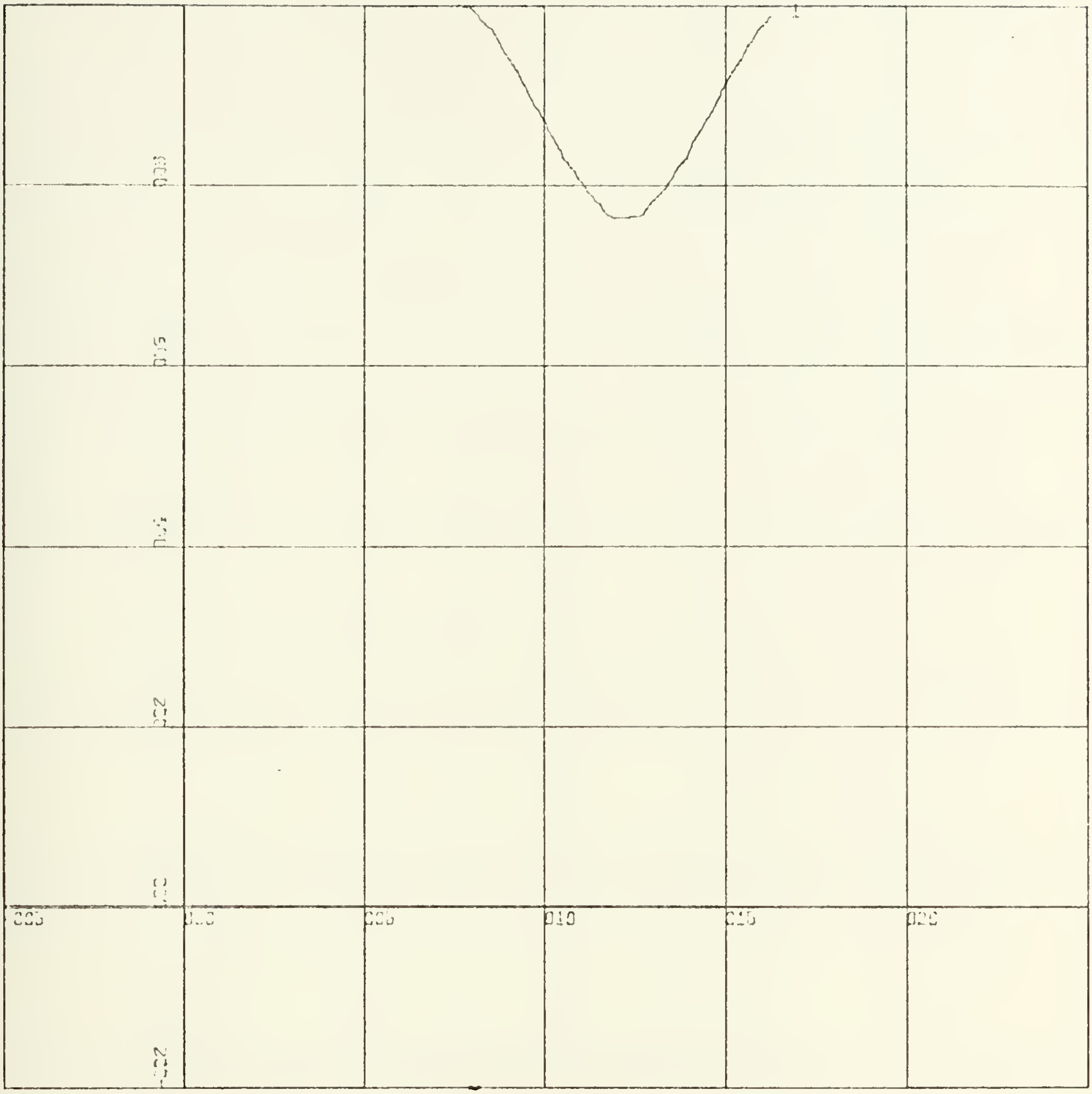

Station 9

X-SCALE=5.00E+00 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.

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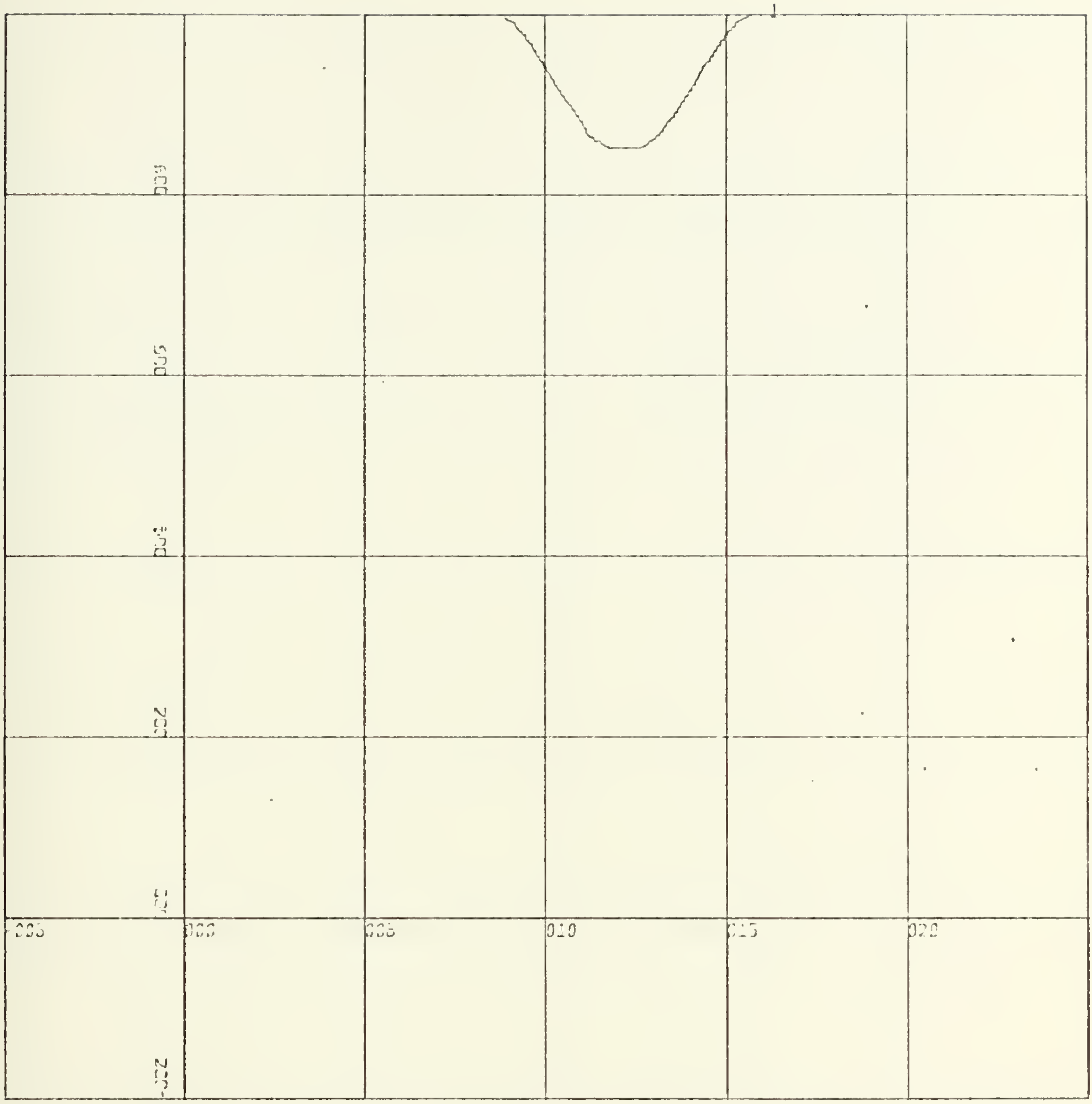
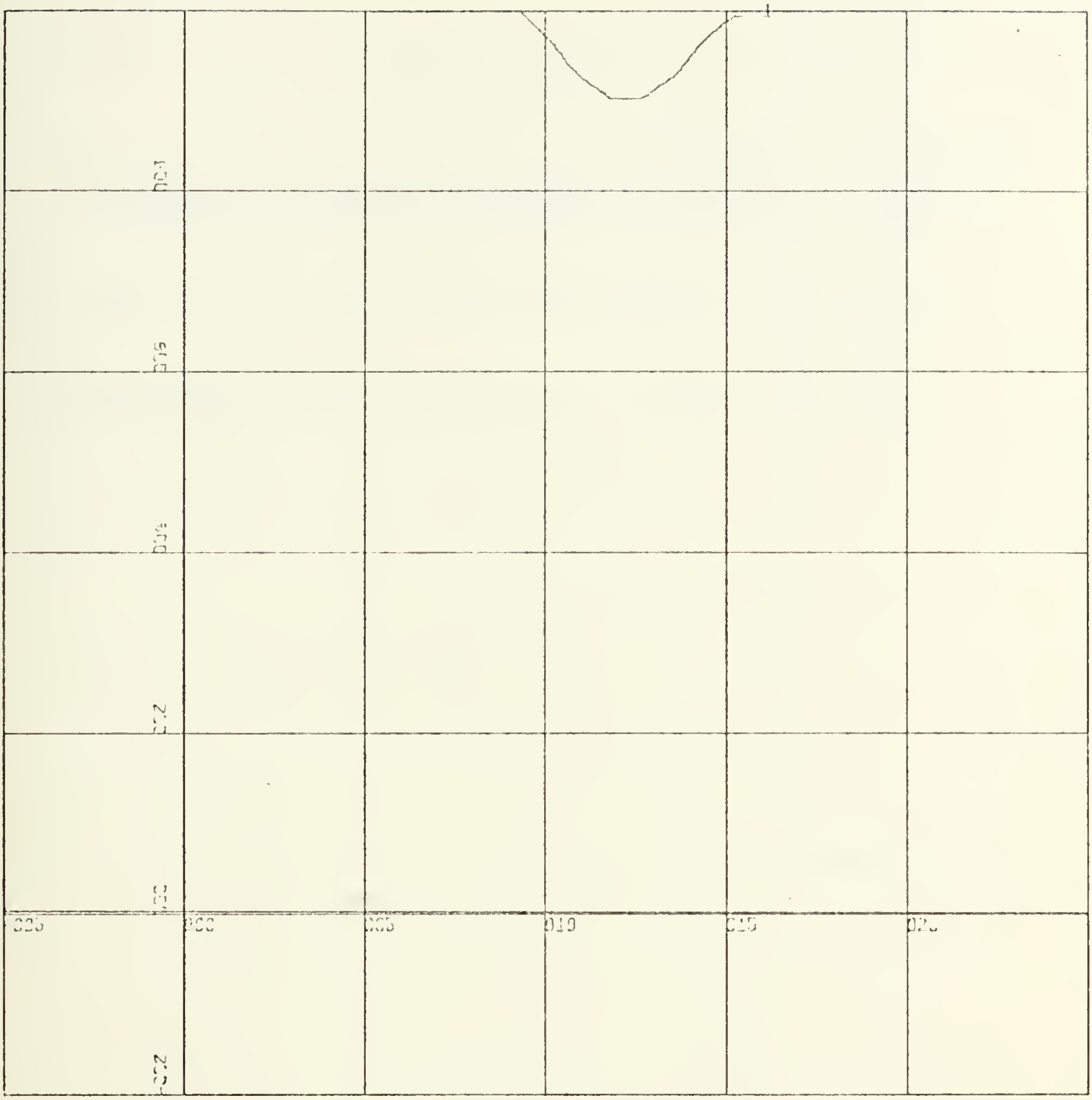


Station 10

X-SCALE=5.00E+00 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.

A PLOT OF THE PITOT-STATIC
VELOCITY RATIO VERSUS POSITION



Station 11

X-SCALE=5.00E+00 UNITS INCH.
Y-SCALE=2.00E-01 UNITS INCH.
A PLOT OF THE PITOT-STATIC
VELOCITY RATIO VERSUS POSITION

LIST OF REFERENCES

1. Anderson, T.E., A Study of Turbulent Wakes in Constant Streamwise Pressure Gradients, MSAE Thesis, Naval Postgraduate School, Monterey, California, 1972.

2. Schlichting, H., Boundary-Layer Theory, McGraw-Hill, 1968.

3. Tennekes, H. and Lumley, J. L., A First Course in Turbulence, MIT Press, 1972.

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13. ABSTRACT

This report was prepared to describe the results of an experimental study of free turbulent mixing in axial pressure gradients. Both the pressure field and the velocity field were extracted using pitot-static probes and both a single normal wire and an X-array hot-wire anemometers. The resulting hot-wire data shwon in Figures 1-80 present an excellent visual representation of the physical aspects of turbulent flow.

An analysis of the results of this experiment show conclusively that the Reynolds Stresses in the flow are related by some function to the turbulent kinetic energy; however, no specific function was found that would produce the relationship observed in this study.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
hot-wire anemometer free turbulent mixing axial pressure gradients						

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K14965
c.1

Kearny

A hot-wire anemometer study of free turbulent mixing in axial pressure gradients.

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A hot-wire anemometer study of free turbulent mixing in axial pressure gradients.

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